ANNEX VI
FINAL NARRATIVE REPORT

- This report must be completed and signed by the Contact person.
- The information provided below must correspond to the financial information that appears in the financial report.
- Please complete the report using a typewriter or computer (***you can find this form at the following address <Specify>)***.
- Please expand the paragraphs as necessary.
- ***Please refer to the Special Conditions of your grant contract and send one copy of the report to each address mentioned***.
- The Contracting Authority will reject any incomplete or badly completed reports.
- Unless otherwise specified, the answer to all questions must cover the reporting period as specified in point 1.6.
- Please do not forget to attach to this report the proof of the transfers of ownership referred to in Article 7.3 of the General conditions.

1. Description

1.1. Name of beneficiary of grant contract: InnoVision Systems

1.2. Name and title of the Contact person: Eng. Ahmed Abdulbaky

1.3. Name of partners in the Action: German University in Cairo (GUC), Center for Telematics (ZfT), Germany and Isteshaar, Egypt

1.4. Title of the Action: MineProbe: A Distributed Mobile Sensor System for Minefield Reconnaissance and Mapping in Egypt

1.5. Contract number: +202 22663063

1.6. Start date and end date of the Action: May 28th, 2014 to May 27th, 2017

1.7. Target country(ies) or region(s): NWC, Egypt

1.8. Final beneficiaries &/or target groups[1] (if different) (including numbers of women and men): Target Groups: Executive Secretariat for the Demining and Development of the North West Coast, Egyptian Ministry of International Cooperation and - Researchers and Industrial Partners. Final Beneficiaries: Deminers, Civilians, Egyptian government, Egyptian society and MENA Region and South-eastern Europe

1.9. Country(ies) in which the activities take place (if different from 1.7): Egypt

[1] “Target groups” are the groups/entities who will be directly positively affected by the project at the Project Purpose level, and “final beneficiaries” are those who will benefit from the project in the long term at the level of the society or sector at large.

2. Assessment of implementation of Action activities

2.1. Executive summary of the Action

Please give a global overview of the Action's implementation for the whole duration of the project

MineProbe is an applied research project funded by EU-Egypt Innovation Fund - Grant Scheme 1. This project tackles a very important problem with socio-economic impact, which is the problem of landmine and unexploded ordnances (UXO) contamination in North West Cost (NWC) of Egypt. MineProbe provides a novel solution to this problem focusing on landmine detection and field mapping. The developed system encompasses a number of spatially distributed unmanned ground vehicles equipped with efficient multimodal landmine detection systems and highly accurate hybrid global localization systems. The system provides a mine map for the minefield that shows the exact locations of the detected landmines and UXOs. This landmine map can be used later by the Army engineers to destroy or deactivate the identified ordnances in the field. This project has a large contribution and relevance to the society, directly by providing mine maps that cover all the infected lands, resulting in decreasing the injuries and save lives as first priority, speeding up the demining process reliably and safely, and allowing for using these lands for economic development of Egypt.

This report summarizes the main findings and activities conducted through the whole period of MineProbe project. The remainder of this report is organized as follows:

- Section 2 highlights the main objectives of MineProbe project.
- Section 3 introduces MineProbe team.
- Section 4 describes the main modules developed through the different MineProbe' work packages.
- Section 5 shows the difference between the developed MineProbe system and other state-of-the-art landmine and UXO detection systems/techniques.
- Section 6 summarizes the main findings and outcomes of MineProbe project.
- Finally, Section 7 presents the different dissemination activities conducted during the whole period of the project.

MineProbe Team

Applicant

InnoVision Systems is a premier systems integrator and solution provider in Egypt. InnoVision Systems covers a wide spectrum of the economic sectors, such as Robotics, Manufacturing automation, Telecom, Oil & Gas, Utilities, Renewable Engineering and Research & Development.

Partners

Robotics and Autonomous Systems (RAS) Research Group, German University in Cairo was founded in 2007 to conduct multidisciplinary research and development activities in the area of robotics and autonomous systems.

Center for Telematics (ZfT), Germany is a research center of excellence that combines advanced methods from telecommunications, automation and informatics to provide services at remote locations. The ZfT addresses advanced methods for tele-operations of equipment in the area of applied research.

Isteshaar is a research-support company dedicated to providing engineering services in the area of sensor technologies.

Associate

The Executive Secretariat for the Demining and Development of the North West Coast of the Ministry of International Cooperation is responsible for the North West Coast Development and Mine Action Plan.

Fig. 1 shows MineProbe team during field trails.

Fig.1 MineProbe team

MineProbe Work Packages

MineProbe was organized around eight interrelated work packages (WP) with 23 tasks (T) as illustrated in Fig. 2. All of these work packages and tasks are vital for the design and development of ideas and solutions.

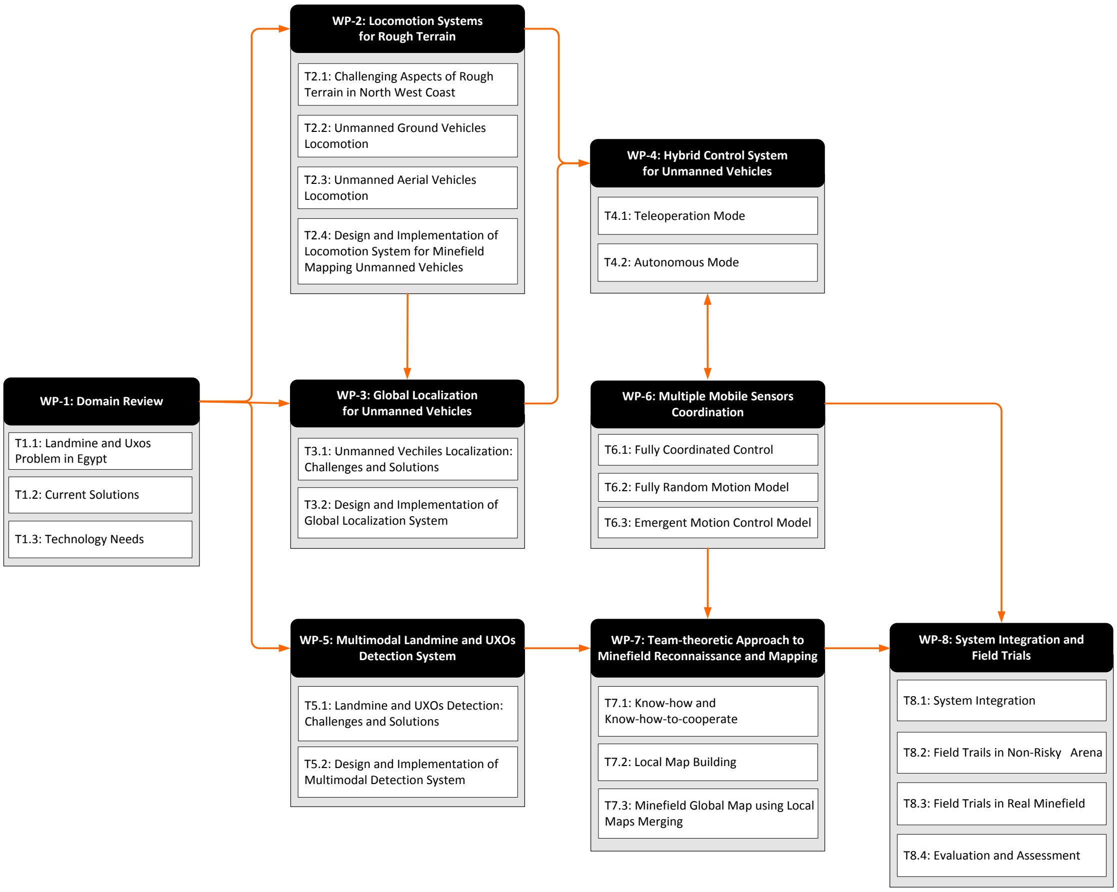


Fig. 2 MineProbe Work Packages and Tasks

The following sections highlight the work accomplished through the different work packages and tasks of MineProbe project.

Domain Review

MineProbe started by conducting a comprehensive survey and analysis on the challenging aspects of the problem of landmine and UXOs contamination in Egypt, the current solutions used to face this problem, and the fundamental requirements for the technology-based solutions which may help to solve this serious problem. The research reviewed existing and emerging technologies for minefield mapping in order to identify common approaches and gaps within the technology landscape. In MineProbe, seven different types of soils (Loam, Sandy Loam, Sand, Dry Sand, Clay, Heavy Clay and Lean Clay) have been identified and characterized in order to design ground vehicles able to negotiate different types of rough terrains. Common anti-personnel landmines in NWC have been also identified as Czech Republic and Slovakia: PP Mi-Sr, which is similar to German S-mine; Russian Federation: PMN and United Kingdom; Mk 2. Dummay objects have been created with same dimensions and material to test the developed multimodal landmine and UXOs detection system. Most of minefield problems are seen by the MEO engineers in terms of detection. They need better ways to detect and locate landmines and UXOs. Once the ordnance has been located, neutralization or destruction can be performed within their capacity. State-of-the-art landmine and UXO close-in and stand-off detection techniques have been surveyed in this work package. The results of this work package have been included in a technical report and a conference paper [Alaa Khamis, Mohammed

Ashraf and Ahmed Abdulbaky, "Landmines and UXOs in NWC: A Domain Review," 2016 International Workshop on Recent Advances in Robotics and Sensor Technology for Humanitarian Demining and Counter-IEDs (Refer to Annex 1 for Domain Review Paper)].

Locomotion System

Vehicle locomotion is the study of how to design vehicle appendages and control mechanisms to allow robots to move fluidly and efficiently. Different kinds of locomotion systems are available with different levels of complexities and motion fluidity and efficiency. Each locomotion system has its properties, complexity, limitations and cost. An efficient locomotion system has been designed with high level of mobility, streerability and maneuverability that allow the vehicles to negotiate rough terrains. Fig. 3 shows the three developed UGVs and their control panel.

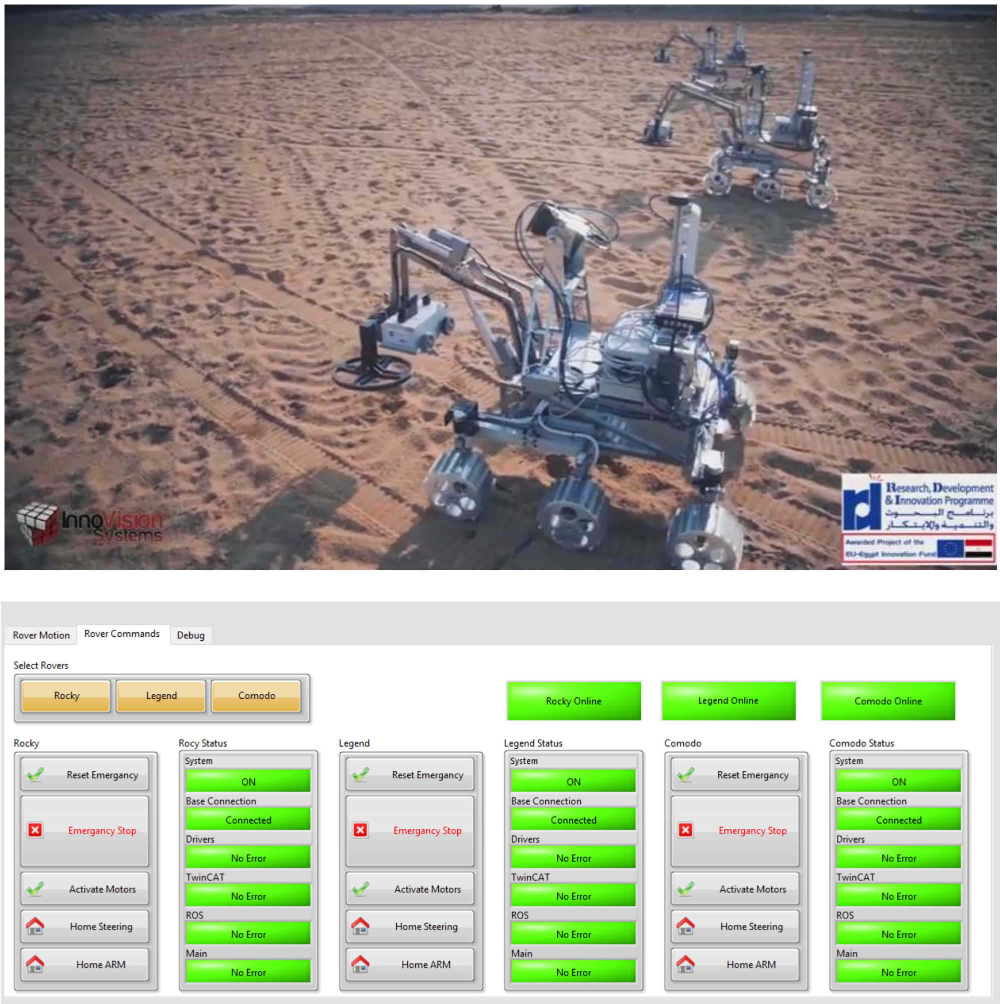


Fig. 3 Control panel of the three UGVs

The results of this work package have been included in a technical report and conference papers [Alaa Khamis and Mohammed Ashraf, "A Differential Evolution-based Approach to Design All-Terrain Ground Vehicle Wheels," The 17th International Conference on Autonomous Robot Systems and Competitions (ICARSC 2017) And Ahmed Abdel Hamid, Amr Nazih, Mohammed Ashraf, Ahmed Abdulbaky and Alaa Khamis, "UGV Locomotion System for Rough Terrain," 2016 International Workshop on Recent Advances in Robotics and Sensor Technology for Humanitarian Demining and Counter-IEDs (RST)]. YouTube video for the field trails is available (Refer to Annex 2 for UGV Locomotion System For Rough Terrain Paper) https://www.youtube.com/watch?v=FP61hqxA2fM

Hybrid Localization System

As mentioned in the project objectives, MineProbe will provide a mine map for the minefield. In this mine map, obstacles will be mapped and the locations of the detected mines and UXOs will be identified. In order to successfully construct this map, the mobile vehicle should be equipped with high precision localization system. In this work package, a centimetre-level global localization system has been developed by integrating GPS, RTK and IMU measurements as illustrated in Fig. 4.

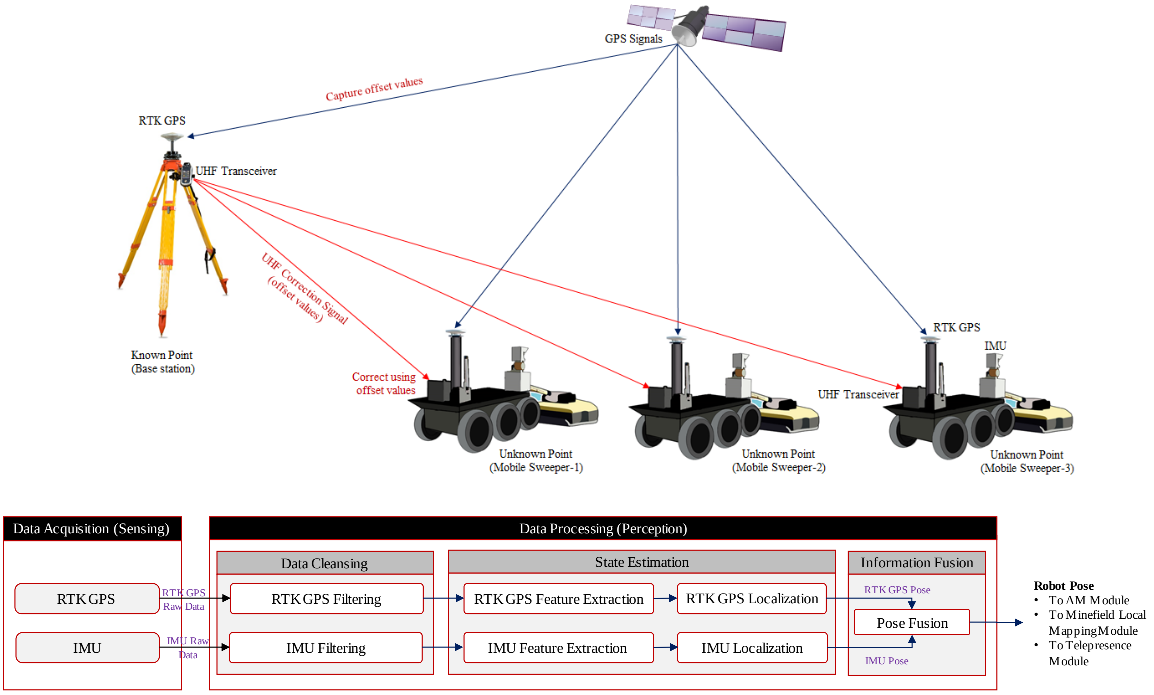


Fig. 4 Hybrid Localization System

The results of this work package have been included in a technical report.

Multimodal Detection System

Nowadays, there is no single sensor technology that has the capability to attain good levels of detection for the available landmines while having a low false alarm rate and low false negative rate under various types of soil, different weather, all types of mines, natural and ground clutters, etc. A modified Bayesian approach has been applied to develop a dual sensor that combines data from EMI sensor and data from GPR sensors. The developed dual sensor achieved lower variance, higher detection rate, lower false alarms and lower false negatives compared to each of the individual sensors used as shown in Table 1.

Table 1 Dual sensor versus EMI and GPR sensors

Metrics/ Sensor	EMI	GPR
Variance	0.11	**0.04**
Probability of detection (Pd)	0.6	**0.8**
Probability of false alarms (PFA)	0.4	**0.27**
Probability of false negatives (PFN)	0.1	**0.08**

The results of this work package have been included in a technical report and a conference paper [Muhammad Aly and Mohammed Ashraf, Alaa Khamis, "GPR and EMI Information Fusion Approach to Landmine Detection," 2016 International Workshop on Recent Advances in Robotics and Sensor Technology for Humanitarian Demining and Counter-IEDs (Refer to Annex 3 GPR and EMI Information Fusion Approach to Landmine Detection Paper)].

Control Modes and Cooperative Mapping

Two modes of motion control have been developed, namely, teleoperation and autonomous mode. In order to facilitate the autonomous modes, a local mapping module has been developed to detect the obstacles in front of the vehicle as shown in Fig. 5.

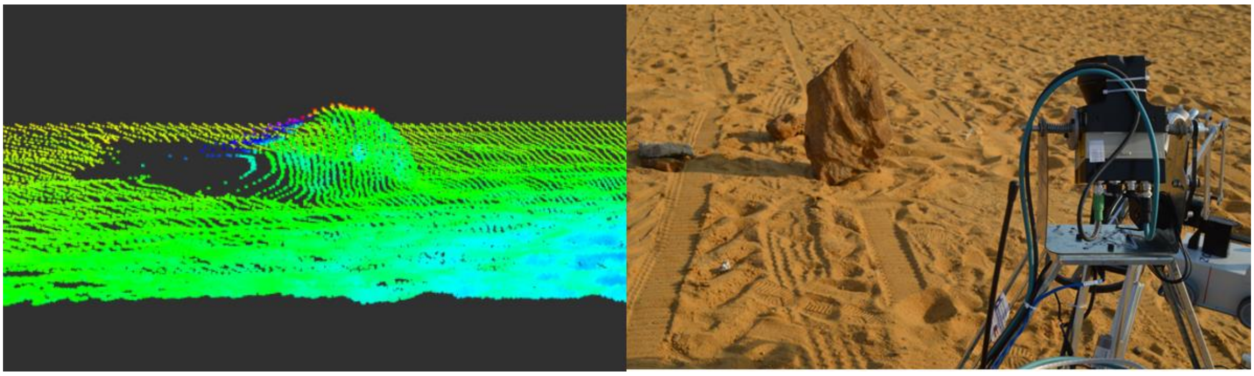


Fig. 5 A local map created by minesweeper during the autonomous motion mode

In both teleoperation and autonomous modes, the landmine and UXO detection and mapping are done automatically without any human intervention. Each vehicle creates a local map for the assigned area of interest in the minefield. Local maps are then integrated to create a global map for the minefield showing the locations of the detected landmines/UXOs. This global map will be then clustered based on the number of available acting agents (deminers) to successfully remove or neutralize the landmines. The locations of the detected landmines/UXOs and their clusters information are visualized and overlaid on high resolution satellite maps as shown in Fig. 6.

Fig. 6 Minefield map created by three minesweepers

This mine map can be used later by the Army engineers to destroy or deactivate the identified ordnances in the field.

Multi cooperation technique

Introduction

We have implemented our multi cooperation module based in approach proposed in[1] . the next sections represent more technical details about the package “mineprobe-mrs”. The package implemented using python over ROS. It implements a technique for divide the task for the multi robot system into small subtasks and pass the subtasks for the system’s agents. In our case, the task is to scan the mine field and cover it. So every agent should know the area it should scan and generate the landmine map for it.

Also the package provide the agent with motion pattern which will use to cover its area. Motion patterns should satisfy the condition of covering the greatest area in less time possible. Several motion patterns available in the literature that helps the multi-agent systems to solve the area coverage problem.

Cooperation systems

System agents are communicating with each others to achieve a specific task. There is diffrent type of cooperation organizing paradigms which variete in the computational time and agents communication technique.
One of the usually used paradigm for multi cooperated agent is the hierarchical architecture. Where the system components are shaped in a tree-like structure. the system can organize in N hierarchical levels which level 1 contains only the system’s main agent and the level N contains the sensing agents.
Hierarchical levels are different in role of agents and authority in the system. Agents in different level or in the same level are communicating with each others through pre defined messages and protocols.

Systems overview

In the proposed hierarchical organizational behavior the systems divided into three levels : Firstly, sensing agents which have the know how to explore and collecting data about the environment. Secondly,micro manager which is communicate and manage with a sub team of sensing agents. Finally, the Macro manager is the main agent of the system which manages the whole micromanagers in the system.
figure [1] shows the proposed hierarchy for the systems components and the relations between them.

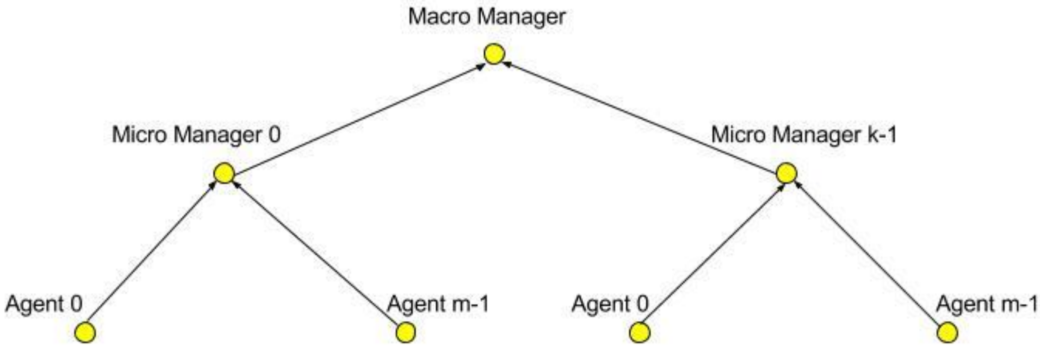


Figure [1]

User communicates with the macro manager of the system and provide oit with the problem boundary, conditions and data . the macro manager divide the problem into subproblems and send it again to the micro managers of the system.
The micro managers are the communication channels between the sensing agents and the macro manager of the system. They received the sub area boundary for the mine field and send foreach sensing agent its area which will scan.
The sensing agents are the soldiers of the game. They are holding the know how to achieve the system's functionality. Sensing agent receive its sub area boundary and the motion model from its team leader (micro manager) and started to follow the motion model to cover the whole area it should cover.

Motion Model for sensing

Different motion models has been proposed in the literature. We have implement 2 types of motion models both are depending on divide and conquer algorithm in the implementation. Motion model defines the method which the scanning agent (sweeper) will perform in order to scan its area.

a) Fully coordinated motion

In this model agents are moving in their area line by line horizontally , where the agents starts from the top-left corner for the area and moves to the top right corner . After that the robot go down for one step. And turns back to the left side of the area. The agent continue to perform this steps till finish its area.
If an object/mine is detected the sensing agent has to record its location then follow a certain path to avoid it. Figure 2 shows an example of two sweepers scanning their area by following the line by line scanning mode, the green shaded area is the sweeper's AOI, the first blue dot is the current position of the agent and the blue dots are the recently visited positions.

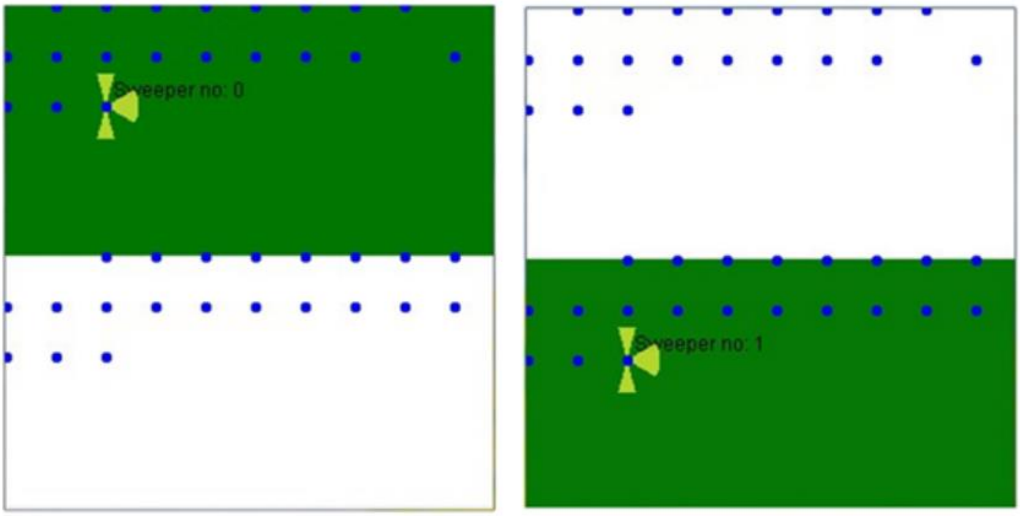


Figure [2]

b) Fully Random Motion

Like the first model in random motion model the scanning agents (sweepers) starts in the top-left of the area it will scan , but in this case the agent select the next step randomly. In this model the agent must save all the steps it have done in order to not go to the visited positions again.

The termination condition in the random motion model can be related to a certain event. In our implementation the termination condition is related to the finishing of the estimated time in order to scan area. Figure 3 shows an example for 2 scanning agents (sweepers) do their tasks using fully random motion approach

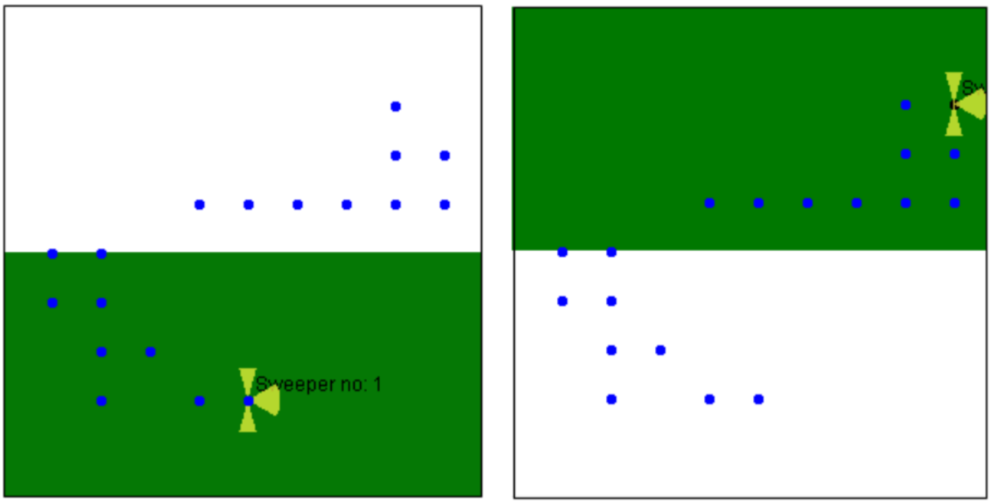


Figure [3]

Every motion model has its own advantages and disadvantages . And any motion model can be suitable for a specific application but will be not efficient for others. In our system the fully coordinated motion model is more efficient due to this reasons:

- The random motion model waste storage resources in order to keep track for the visited positions through the system running time which is not efficient in systems that uses small storage size.
- The random motion model doesn’t guarantee to cover the whole area for the agents. Because its termination condition is related to the time not the scanning area.

ROS in multi cooperation systems

ROS is a framework for programming on robots. ROS has several number for ready to use packages that implements numerous algorithm for several problems related to robotics. every robot system working over ROS has its master program. The ROS master is the main program which handles the messages between the ros system components So without master the systems will fail to achieve its main function.

In our system every rover running its master. So it should be a method for handling the communication between all the ros masters running, and between rovers and the base station. ROS package "multimaster_fkie"[2] is one of the solutions for achieving this function. The package establish the network for multi master running in the system. It helps these master to communicate with each others by sending and receiving messages. Also the package handles the communication protocol of translating messages over the network.

The main 2 nodes of the system is

a) master_discovery

This node sends periodically multicast messages to the network of the masters in order to make the ROS master aware for each other. Also the node notify the masters network with the changes happened in each master.

b) master_sync

This node register the topics and services for the other masters available in the network to the local master. Also every there is any changed on these topics or service the node update the information about that topics or services. The node can manage which topics and services should be considered and which should ignored.

The master_sync node only synchronizes remote topics or services to the local master. In order to do the opposite, the remote master must have its own master_sync node. The multimaster_fkie solution only supports topics and services, however actions are implicitly supported because they are build on top of 5 topics.

Similarly to what happens in a standard ROS system, once the topics, services and/or actions are registered on the remote ROS sub-systems, a point to point socket is created to directly connect two or more nodes, and the multi-master mechanism is not used until there is a change in the configuration (a new publisher/subscriber appears or an existing one disappears, etc.).

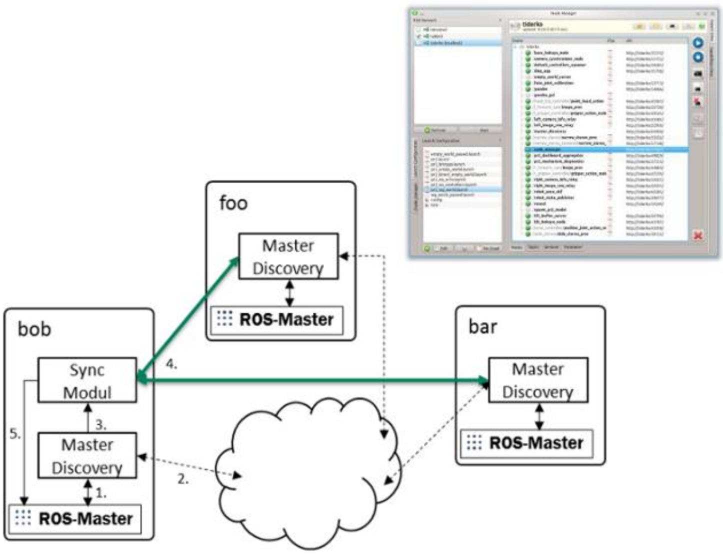


Figure [4]

Figure 4 shows a simple example for a multi master system every single master system is running the node of master discover . but some of them are running master_sync in order to get the update happened on the network

Implementation details

We have implement the mentioned approach in a ROS package called mineprobe_mrs . the implementation is done using python and running over indigo and later version of ROS. the package consists of 3 main nodes “macro,micro and sweeper” nodes.

i) Macro

The node receives the boundary of the minefield and the number of micro managers in the system. It publishes the area boundary for each micro managers which will be scanned by its team.

After sending all the data needed by the micro managers. Macro manager wait for the local minefield maps from all the micromanager and merge them all in landmine map.

ii) Micro

Node receives the boundary of its area its team should scan and number of sweepers under its control. After dividing the received area it send for each sweeper the area it will scan.

Like macro manager, micro manager wait for the local minefield maps from all the sweepers and merge them all in landmine map.

iii) Sweeper

Sweeper is the agent which know how to know process the main function from the system ,which is scanning the area, in our case. Sweeper wait for the area boundary and the start location for the scanning area.

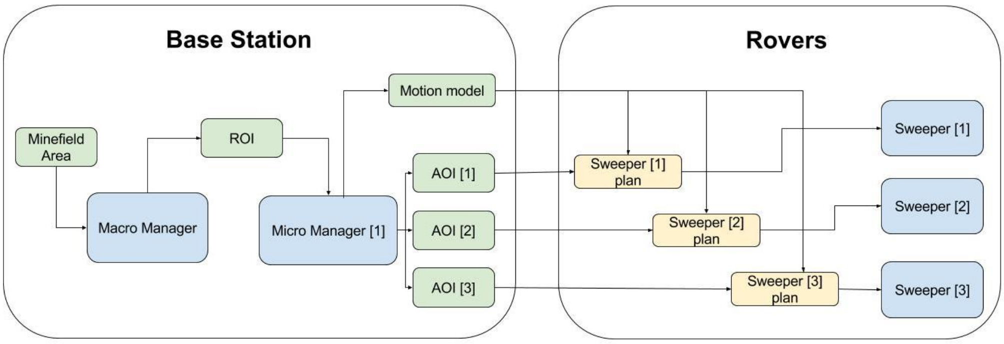


Figure [5]

Figure [5] shows the system hierarchy , where the macro and micro managers nodes running on the base station side . and the sweeper node running on the rovers side.

The system wait for the landmine field area size from the user and pass it to the Macro manager. The macro manager split it into smaller ROIs area and pass it to the Micro managers (1 in our case). Then the Micro split the ROI into AOIs and pass them to the sweepers. The sweeper take the motion model and area size as an inputs for its plan and starts to scan and send the local map back to the micro manager and then to the macro manager.

References

[1] ElGindy, Asser, and Alaa Khamis. "Team-theoretic approach to cooperative multirobot systems: Humanitarian demining as a case study." Engineering and Technology (ICET), 2012 International Conference on. IEEE, 2012.

[2] Alexander Tiderko. multimaster_fkie. http://wiki.ros.org/multimaster_fkie, October 2014.

MineProbe versus other Systems

The following subsections show comparison between the developed MineProbe system and other state-of-the-art landmine and UXO detection systems/techniques.

a) MineProbe versus Human Deminers

Table 2 shows a comparison between MineProbe and human deminer.

Table 2 MineProbe versus Human Deminer

Metrics	Human Deminer	MineProbe
Area coverage per day (8 hours)	15-20 m^2	170 m^2
Digital mapping	No	Yes
False alarms	High	Low
False negatives	High	Low
Working in harsh environments	No	Yes
Safety	1 deminer is killed and 2 injured for every 5000 successfully removed mines.	No safety concerns

b) MineProbe versus Biological Techniques

Table 3 shows a comparison between MineProbe and biological detection techniques using dogs, rats or bees.

Table 3 MineProbe versus Biological Techniques

Metrics	Rats/Dogs/Bees/Flies	MineProbe
Need for training	Yes	No
Need for guidance	Yes	No
Weight	Lighter	Heavier
Digital mapping	No	Yes
Permanency of detection capability	No	Yes
Ease of duplication	No	Yes
Working in harsh environments	No	Yes

c) MineProbe versus Husky 2Gs

Table 4 shows a comparison between MineProbe and state-of-the-art Husky 2G.

Table 4 MineProbe versus Husky 2G

Metrics	Husky 2G	MineProbe
Mounting	Manned	Unmanned
Degrees of Mobility	2	2
Degrees of Steerability	1	4
Degrees of Maneuverability	3	6
Engine	6.4L six-cylinder turbo diesel	DC Motors
Speed	60 km/h	0.54 km/h
Weight	2.9 Ton	60 Kg
Dual sensors	Yes	Yes
Capabilities	Detection and disposal	Detection and mapping
Cost	Much more expensive	Cheaper

As can be seen, MineProbe is designed and developed using state-of-the-art technology and intelligent approaches to provide efficient, reliable, adaptive and cost-effective solution for the serious problem of humanitarian demining in Egypt and other affected countries in the world.

MineProbe: A Summary

The main outcome of MineProbe can be summarized as follows:

- A detailed study about challenging aspects of the problem of landmine and UXOs contamination in NWC.
- An efficient vehicle locomotion system to endow UGVs with ability to move fluidly and efficiently in rough terrain of NWC.
- Teleoperated and autonomous control modes for the UGVs.
- A centimeter-level accuracy outdoor hybrid localization system for unmanned ground vehicles.
- A GPR-EMI dual sensor for landmine detection with high detection rates and low false alarms.
- A minefield reconnaissance and mapping system that encompass a number of spatially distributed mobile sweepers able to sample the minefield at different locations, exchange the information with other agents, and collaboratively create a mine map for the minefield. In this mine map, the locations of the detected mines and UXOs are identified.

MineProbe system can be used during the second phase of quality assurance process. Human supervisor is the final decision maker.

Table 5 summarizes the mean features of the developed vehicles for minefield reconnaissance and mapping in Egypt.

Table 5 MineProbe Specifications

MineProbe	Specs
Speed	0.54 km/h
Area coverage	21 m^2/hr
Battery duration	3 hours
Degrees of Mobility	2
Degrees of Steerability	4
Degrees of Maneuverability	6
Multimodal detection system	Dual sensor with high detection rate, very low false alarms and false negatives
Localization system	Centimeter-level hyper localization system
Mapping	Digital mapping capability

A video for the field trails is available here: https://www.youtube.com/watch?v=FP61hqxA2fM

Dissemination Activities

The following dissemination activities have been conducted to raise the awareness about the problem of humanitarian demining and the findings of MineProbe project. In all these dissemination activities, the financial support received from the contracting authority has been acknowledged.

a) Workshops

The following workshops have been organized and/or technically sponsored by MineProbe team:

- MineProbe Final Workshop, Dusit Thani LakeView, New Cairo, May 27, 2017.
- Second International Workshop on Recent Advances in Robotics and Sensor Technology for Humanitarian Demining and Counter-IEDs (RST 2016), October 27-30, 2016.
- Second MineProbe workshop, Cairo in October 27, 2015
- First workshop, Radisson Blue Hotel, Cairo, September 6, 2014

b) Technical Challenges

MineProbe team technically sponsored Minesweepers: Towards a Landmine-free World, outdoor robotic competition at Zewail City of Science and Technology, October 27-30, 2016.

c) Keynote Speeches and Webinars

MineProbe's PI has given the following keynote speeches and webinars:

- Humanitarian Robotics: Minefield Reconnaissance and Mapping at Robotics and Automation for Humanitarian Applications (RAHA - 2016) in December 18-20th 2016, Amrita University, Kerala, India.
- "Humanitarian Demining: Facts, Technology Enablers and Initiatives" in the Workshop on Recent Advances on Robotics and Sensor Technology for Humanitarian Demining at The 6th

International Conference on Computing and Informatics in Northern Chile (INFONOR-Chile 2015).

- Cooperative Multi-robot Systems, Egypt Scholars Webinar in July 23, 2016.

d) Media Interviews

MineProbe's PI have the following media interviews about the project:

- EEWeb Interview
- Egypt Time, Al-Araby TV, London
- Youm7
- Antofagasta, Chile TV

e) Papers

The following papers have been published:

- Alaa Khamis and Mohammed Ashraf, "A Differential Evolution-based Approach to Design All-Terrain Ground Vehicle Wheels," The 17th International Conference on Autonomous Robot Systems and Competitions (ICARSC 2017).

- Alaa Khamis, "Minefield Mapping using Distributed Mobile Sensors", Robotics and Automation for Humanitarian Applications (RAHA - 2016).

- Muhammad Aly and Mohammed Ashraf, Alaa Khamis, "GPR and EMI Information Fusion Approach to Landmine Detection", Second International Workshop on Recent Advances in Robotics and Sensor Technology for Humanitarian Demining and Counter-IEDs (RST 2016).

- Alaa Khamis, Mohammed Ashraf and Ahmed Abdulbaky, "Landmines and UXOs in NWC: A Domain Review", Second International Workshop on Recent Advances in Robotics and Sensor Technology for Humanitarian Demining and Counter-IEDs (RST 2016).

- Ahmed Abdel Hamid, Amr Nazih, Mohammed Ashraf, Alaa Khamis, "UGV Locomotion System for Rough Terrain," Second International Workshop on Recent Advances in Robotics and Sensor Technology for Humanitarian Demining and Counter-IEDs (RST 2016).

f) Technical Reports

The following technical reports have been produced:

- WP-1: Domain Review
- WP-2: Locomotion Systems for Rough Terrain
- WP-3: Global Localization for Unmanned Vehicles
- WP-4: Hybrid Control System for Unmanned Vehicles
- WP-5: Multimodal Landmine and UXO Detection System
- WP-6: Multiple Mobile Sensors Coordination
- WP-7: Team-theoretic Approach to Minefield Reconnaissance and Mapping
- WP-8: System Integration and Field Trials

g) Website

MineProbe maintains an updated website (http://www.mineprobe.org/) that disseminates knowledge about the problem of landmine and UXO contamination in Egypt and presents the MineProbe project and its key findings.

2.2. Activities and results

Please list all the activities in line with Annex 1 of the contract since the last interim report if any or during the reporting period

Activity 1:

Title of the activity: Conference at location W with X participants for Y days on Z dates

Topics/activities covered <please elaborate>:

Reason for modification for the planned activity <please elaborate on the problems - including delay, cancellation, postponement of activities, change in target, etc - which have arisen and how they have been addressed> (if applicable):

Results of this activity <please quantify these results, where possible; refer to the various assumptions of the Logframe>:

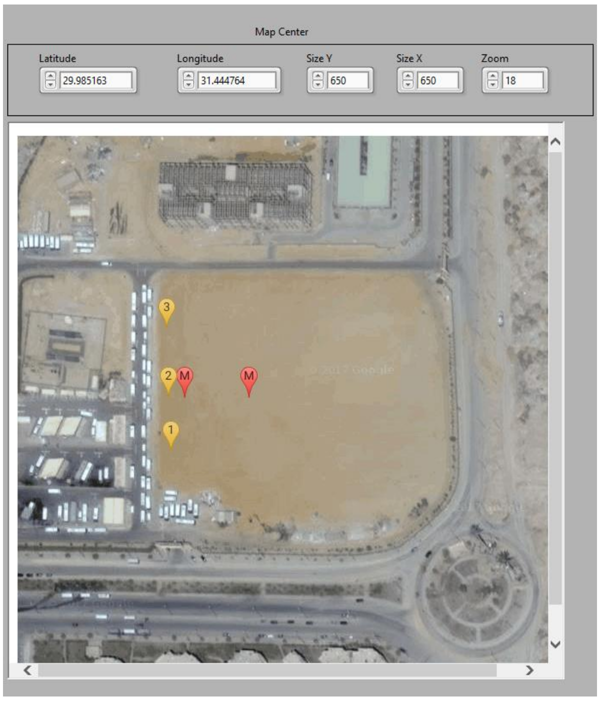
Activity 1: Action Work packages progress

WP-6: Multiple Mobile Sensors Coordination

This work package addressed the interdependency management among the developed unmanned ground vehicle equipped with multimodal detection system in order to achieve their goals in scanning the minefield. Different minefield sweeping strategies are studied including random mobility, and coordinated mobility.

WP-7: Team-theoretic Approach to Minefield Reconnaissance and Mapping

This work package addressed the development of a team-theoretic approach to endow the mobile sweepers with know-how and know-how-to-cooperate capabilities. In this work package, local maps created by individual mobile sensors are integrated to create a global map for the minefield showing the locations of the detected landmines/UXOs. This global map will be then clustered based on the number of available acting agents (deminers) to successfully remove or neutralize the landmines. The locations of the detected landmines/UXOs and their clusters information will be visualized and overlaid on high resolution satellite maps.



WP-8: System Integration and Field Trials

In this work package, the developed components of MineProbe were fully integrated. The integrated system was deployed and tested in a non-risky arena. A simulated minefield was set up at German University in Cairo to mimic a real minefield. Most of the arena will be sandy soils or rocky with obstacles, some steep inclines, ditches and culverts that can be difficult to negotiate by the unmanned vehicles. The arena contains two different objects (without explosive materials) with the exact dimensions, material and profile of the landmine and UXOs used to be found in the NWC. Some of these objects were buried and others were above surface. MineProbe system was tested and its performance was evaluated based on a set of Measures of Performance (MOPs), such as safety, task completion time, false alarm rate, area coverage, reliability, etc.

User interface of part of the robots monitoring & control program showing the status of each robot

Activity 2: Dissemination activities

A number of dissemination activities have been conducted to raise the awareness about the problem of humanitarian demining and the findings of the action. In all these dissemination activities, the financial support received from the contracting authority has been acknowledged. These dissemination activities included the following:

- **MineProbe Final Workshop:** *Workshop* at *Dusit Thani LakeView – Dusit Ballroom in New Cairo* with *100 participants/guests* for One full day on *May 27, 2017*.

  EU, RDI and different government delegation attended this workshop. MineProbe team exposed the developed vehicles and shared with the audience the different accomplishment of MineProbe project.

Stage loaded with the 3 rovers at Dusit Thani ballroom

- ***The 17th International Conference on Autonomous Robot Systems and Competitions (ICARSC 2017):*** *Conference at Convento São Francisco, in Coimbra, Portugal on April 26-28th, 2017*

  Mineprobe Team conducted a technical paper session on Field Robotics :
  - Alaa Khamis and Mohammed Ashraf : A Differential Evolution-based Approach to Design All-Terrain Ground Vehicle Wheels

- ***Humanitarian Robotics:*** *Minefield Reconnaissance & Mapping : Talk at Robotics and Automation for Humanitarian Applications (RAHA – 2016) , Amrita University, Kerala, India for Three Days on December 18-20th, 2016.*

  MineProbe PI conducted a talk entitled "Humanitarian Robotics: Minefield Reconnaissance and Mapping"

- ***MineProbe Workshop :** Workshop at Zewail City of Science and Technology for Three Days on October 27-30th, 2016.*

MineProbe workshop will take place in conjunction with Second International Workshop on Recent Advances in Robotics and Sensor Technology for Humanitarian Demining and Counter-IEDs (RST 2016) to be hosted by Zewail City of Science and Technology in the beautiful city of Cairo, Egypt in October 27-30, 2016. MineProbe workshop is dedicated to present the progress of the different work packages the project.

- ***Second International Workshop on Recent Advances in Robotics and Sensor Technology for Humanitarian Demining & Counter-IEDs (RST 2016):** Workshop at Zewail City of Science and Technology for Three Days on October 27-30th, 2016.*

RST 2016 is organized by MineProbe team in collaboration with Zewail City of Science and Technology and IEEE RAS Special Interest Group on Humanitarian Technology (RAS-SIGHT). RST is designated for reporting recent research and development results in robotics and sensor technologies for humanitarian demining and the recent advances in Counter Improvised Explosive Device (IED) technologies. Detection and removal of landmines and improvised explosive devices, at the present time, is a serious problem of political, economic, environmental and humanitarian dimensions in many countries over the world. The workshop featured plenary speeches, technical paper session, industrial panel session, and an exhibition of humanitarian demining and counter-IED technologies.

The MineProbe Team had 3 Technical paper sessions to conduct in the RST 2016 , Program agenda can be found at this link :

- Muhammad Aly and Mohammed Ashraf, Alaa Khamis, "GPR and EMI Information Fusion Approach to Landmine Detection", InnoVision Systems, Egypt

- Alaa Khamis, Mohammed Ashraf and Ahmed Abdulbaky, "Landmines and UXOs in NWC: A Domain Review", InnoVision Systems, Egypt

- Ahmed Abdel Hamid, Amr Nazih, Mohammed Ashraf, Alaa Khamis , "UGV Locomotion System for Rough Terrain", InnoVision Systems, Egypt

- Mohammed Ashraf and Alaa Khamis , "Design of Robot Wheels for Rough Terrain - A Multi-criteria Optimization Approach", InnoVision Systems, Egypt

- ***EEWeb Interview:** Interview at EEWeb for Three Days Published on December 21, 2015 :* http://www.eeweb.com/spotlight/interview-with-dr.-alaa-khamis

MineProbe's PI has been interviewed by EEWeb to talk about MineProbe project and Minesweepers competition.

2.3. Activities that have not taken place

Please outline any activity and/or publications foreseen in the contract, that have not taken place, explaining the reasons for these

N/A

2.4. What is your assessment of the results of the Action? Include observations on the performance and the achievement of outputs, outcomes, impact and risks in relation to specific and overall objectives, and whether the Action has had any unforeseen positive or negative results. (Please quantify where possible; refer to Logframe Indicators).

We are satisfied with the final outcome and results because we were engaged with state-of-the-art sensors, different programming and development platforms, different design practices, simulation tools and field testing & verifications. As the project was aiming to provide a number of prototypes of mobile robots, we pushed further towards a near-final product. Further details are discussed in section 2.10

2.5. What has been the outcome on both the final beneficiaries &/or target group (if different) and the situation in the target country or target region which the Action addressed?

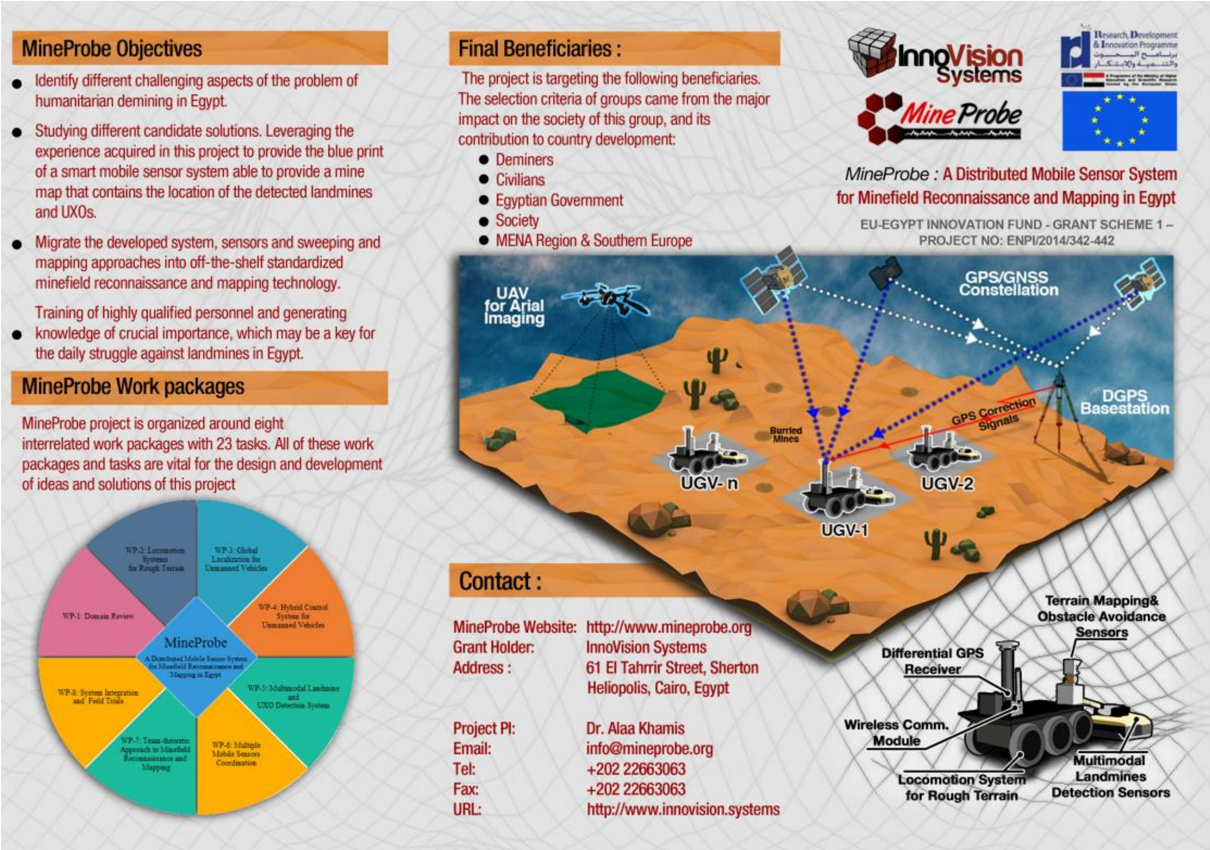
The project has accomplished its planned objectives. The main outcome of this project were the following:

- A detailed study about challenging aspects of the problem of landmine and UXOs contamination in Egypt, the socio-economic impact of the problem and existing and emerging technologies.
- An efficient vehicle locomotion system to endow UGVs with ability to move fluidly and efficiently in rough terrain of NWC.
- Teleoperated and autonomous control modes for the UGVs.
- A centimetre-level accuracy outdoor hybrid localization system for unmanned ground vehicles.
- A GPR-EMI dual sensor for landmine detection with high detection rates and low false alarms.
- A vertically articulated 3-DOF robot arm for the inspection platform.
- A minefield reconnaissance and mapping system that encompass a number of spatially distributed mobile sweepers able to sample the minefield at different locations, exchange the information with other agents, and collaboratively create a mine map for the minefield. In this mine map, the locations of the detected mines and UXOs are identified.

2.6. Please list all materials (and no. of copies) produced during the Action on whatever format (please enclose a copy of each item, except if you have already done so in the past).

Please state how the items produced are being distributed and to whom.

First Brochure: for Kick-off meeting



MineProbe Objectives

- Identify different challenging aspects of the problem of humanitarian demining in Egypt.
- Studying different candidate solutions. Leveraging the experience acquired in this project to provide the blue print of a smart mobile sensor system able to provide a mine map that contains the location of the detected landmines and UXOs.
- Migrate the developed system, sensors and sweeping and mapping approaches into off-the-shelf standardized minefield reconnaissance and mapping technology.
- Training of highly qualified personnel and generating knowledge of crucial importance, which may be a key for the daily struggle against landmines in Egypt.

MineProbe Work packages

MineProbe project is organized around eight interrelated work packages with 23 tasks. All of these work packages and tasks are vital for the design and development of ideas and solutions of this project

Final Beneficiaries :

The project is targeting the following beneficiaries. The selection criteria of groups came from the major impact on the society of this group, and its contribution to country development:

- Deminers
- Civilians
- Egyptian Government
- Society
- MENA Region & Southern Europe

InnoVision Systems

MineProbe

MineProbe : A Distributed Mobile Sensor System for Minefield Reconnaissance and Mapping in Egypt

EU-EGYPT INNOVATION FUND - GRANT SCHEME 1 – PROJECT NO: ENPI/2014/342-442

Contact :

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Grant Holder:	InnoVision Systems
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Front face of first Brochure

About MineProbe

MineProbe project aims at developing a novel minefield reconnaissance and mapping system in Egypt focusing on North West Coast (NWC) as location of the project. This system encompasses a number of spatially distributed unmanned vehicles equipped with different types of sensors to detect obstacles, mines and unexploded ordnances. The action involves collaboration between researchers, experts in their fields, from academic, industrial and governmental institutions pooling their talents to find innovative solutions to the problem of reconnaissance and mapping in Egypt.

Funding Agency

MineProbe is funded by Research, Development and Innovation (RDI) Scheme 1 Programme.

RDI is a Programme of the Ministry of Higher Education and Scientific Research funded by the European Union.this project

Main Applicant

InnoVision Systems is a premier systems integrator and solution provider in Egypt. InnoVision Systems covers a wide spectrum of the economic sectors, such as Manufacturing, Telecom, Oil & Gas, Utilities, Biomedical Devices, Green Engineering and Research & Development.

Partners

GUC Robotics and Autonomous Systems (RAS) Research Group, German University in Cairo was founded in 2007 to conduct multidisciplinary research and development activities in the area of robotics and autonomous systems.

ZfT Center for Telematics (ZfT), Germanyis a research center of excellence that combines advanced methods from telecommunications, automation and informatics to provide services at remote locations. The ZfT addresses advanced methods for tele-operations of equipment in the area of applied research.

ISTESHAAR Innovative Engineering Solutions Isteshaar is a pioneer in providing modularized solutions that support both research and industry. The solutions provided can be used as stand-alone systems, or integrated into more complex systems.

Associate

UNDP The Executive Secretariat for the Demining and Development of the North West Coast of the Ministry of International Cooperation is responsible for the North West Coast Development and Mine Action Plan.

MineProbe

www.mineprobe.org

Landmine in NWC

Egypt has been listed as the country most contaminated by landmines in the world with an estimate of approximately 22.7 million landmines and other unexploded ordinances (UXOs). It is estimated that there are 17.2 million of landmines and UXOs in the North West Coast (NWC). The National Development Plan of Egypt identified immense resources to benefit local dwellers and the overall economic development of the region, including 500,000 acres of land good for agriculture and 3.5 million acres good for grazing; 70 million cubic meter of mineral resources; 1.8 billion barrel of oil and and 8.5 trillion Cubic meter of natural gas.

The humanitarian demining activities carried-out to remove landmines and UXOs from the vast contaminated areas in Egypt are not on the same level of the problem. Following the conventional techniques, the mission of removing a great numbers of landmines would be very slow, labor intensive, costly, inefficient, extremely dangerous and stressful process

To the best of our knowledge, the action presented here will be the first effort that involves collaboration of researchers, experts in their fields, from academic, industrial and governmental institutions pooling their talents to find innovative solutions to the problem of reconnaissance and mapping in NWC.

www.mineprobe.org

Backward face of first Brochure

Second Brochure: designed for the final workshop held at Dusti Thani hotel,

وصف المشروع:

يهدف المشروع الى تصميم منظومة إستشعار موزعة للإستطلاع ورسم خرائط الألغام الأرضية في مصر. تحتوى هذه المنظومة على مركبات أرضية غير مأهولة يتم التحكم فيها عن بعد أو ذاتية التحكم لضمان سلامة الافراد خلال عملية البحث عن الألغام الأرضبة ومخلفات الحروب التى لم تنفجر. تم تصميم منظومات الحركة لتلك المركبات بشكل يضمن درجة حرية حركة عالية فى الاماكن الوعرة. تحتوى كل مركبة على منظومة إستشعار متقدمة لإكتشاف الالغام الأرضية ومخلفات الحروب الغير منفجرة بالإضافة الى منظومة تحديد مواقع دقيقة. تعتمد منظومتى الإستشعار وتحديد المواقع على تقنيات دمج البيانات المكتسبة من مصادر إستشعار متعددة للحصول على درجة عالية من الدقة والموثوقية فى الكشف عن الالغام وتحديد أماكنها ورسم خريطة لأماكن تواجدها. يمكن إستخدام هذه الخرائط للتخلص من الالغام الأرضية ومخلفات الحروب او لإبطال مفعولهم.

بالإضافة الى حرمان مصر من الاستفادة طوال العقود الماضية من عائد تنمية الموارد الطبيعية الهائلة بتلك المناطق التي هي حاليا رهينة للألغام. تتمتع المناطق الموبوءة بالعديد من المصادر الطبيعية والثروات التى يمكن أن تساعد فى تنمية ودعم الاقتصاد المصرى.

وقد قام الجيش المصرى بمجهودات عظيمة لتطهير منطقة العلمين من الألغام للبدء فى مشروع تنمية الساحل الشمالى الغربى والذى يهدف الى توطين 5 ملايين مصرى وتوفير مليون ونصف فرصة عمل. ويشتمل هذا المشروع الطموح على إقامة مدينة العلمين الجديدة على مساحة 88 الف فدان، يقام فيها مركز سياحي عالمي بمساحة 2420 فدان ومدينة ترفيهية بيئية على مساحة 3050 فدان، ومنطقة سياحية جنوب مارينا.

فى هذا المشروع تم التركيز على مشكلة تحديد اماكن الالغام الارضية ورسم خريطة للأماكن الموبوءة باستخدام منظومة دمج بيانات مكتسبه من مستشعرات مختلفة محمولة على مركبة أرضية غير مأهولة يتم التحكم فيها عن بعد. يتم فى هذه الخريطة إظهار مواقع الالغام بدقة مما يسهل التعامل معها لاحقا. سوف يؤدى هذا المشروع البحثى الى تطوير تقنيات إستطلاع حقول الألغام ورسم الخرائط ليجعلها أكثر موثوقية وكفاءة وأمنا على حياة الأفراد مما يساهم فى تطهير المناطق الموبوءة بالالغام الأرضية ومخلفات الحروب فى مصر وكثير من الدول الاخرى فى افريقيا أو آسيا وامريكا اللاتينية وشرق اوربا.

جدوي المشروع ومدي الإفادة للمواطنين:

تعد مشكلة الألغام الأرضية مشكلة ذات بعد سياسى وتنموى وإنسانى، وعادة مايقال أن اللغم هو "الجندى المثالي الذى يدمر ولايأكل ولاينام ويستمر فى الخدمة لسنوات طويلة". ونتيجة لهذا الإعتقاد فقد تكالبت العديد من الدول على التوسع في إستخدام الألغام فى الصراعات العسكرية الدولية والتي يستمر تأثيرها إلى مابعد انتهاء النزاعات مخلفة ورائها اكثر من 110 مليون لغم ومخلفات حروب لم تنفجر فى أكثر من 68 دولة ينجم عنها أكثر من 5000 حالة وفاة أو الاصابة بالعمى أو الحروق أو بتر الاعضاء (أكثر من 46% منهم أطفال) بالإضافة الى مابين 15 إلى 20 ألف إصابة اخرى سنويا وملايين النازحين. هذا وتصنف مصر عالميًا مصر من أكثر دول العالم تلوثا بالألغام الأرضية وخامس دول العالم من حيث عدد الألغام بالنسبة للمساحة حيث تحتوى على ما يقرب من 22.7 مليون لغم ومخلفات حروب لم تنفجر يتركز معظمهم فى الساحل الشمالى وفى بعض مناطق البحر الأحمر وخليج السويس.يشكل وجود هذا العدد الهائل من الألغام الأرضية و الذخائر غير المتفجرة التى لم تنفجر تهديدا خطيرا لحياة وسلامة البشر ممن يرتادون هذه المناطق الموبوءة

Contact DETAILS

Project PI: Dr. Alaa Khamis

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InnoVision Systems · Mine Probe · Research, Development & Innovation Programme

MINEPROBE:
A Distributed Mobile Sensor System for Minefield Reconnaissance & Mapping in Egypt

منظومة إستشعار موزعة للإستطلاع ورسم خرائط الألغام الأرضية في مصر

EU-Egypt Innovation Fund Grant Scheme 1
EuropeAid/132-715/M/ACT/EG

برنامج تابع لوزارة التعليم العالي والبحث العلمي ممول من الإتحاد الاوروبي

MINEPROBE.ORG

About MineProbe

MineProbe aims at developing a novel minefield reconnaissance and mapping system in Egypt focusing on North West Coast (NWC) as location of the project. MineProbe encompasses a number of spatially distributed unmanned ground vehicles (UGVs) equipped with multimodal landmine and unexploded ordnances (UXO) detection systems. The system provides a mine map for the minefield that shows the exact locations of the detected landmines and UXOs. This landmine map can be used later by the Army engineers to destroy or deactivate the identified ordnances in the field. This project has a large contribution and relevance to the society, directly by providing mine maps that cover all the infected lands, resulting in decreasing the injuries and save lives as first priority, speeding up the demining process reliably and safely, and allowing for using these lands for economic development of Egypt.

Funding Agency

MineProbe is funded by Research, Development and Innovation (RDI) Scheme 1 Programme. RDI is a Programme of the Ministry of Higher Education and Scientific Research funded by the European Union.

Applicant

InnoVision Systems is a premier systems integrator and solution provider in Egypt. InnoVision Systems covers a wide spectrum of the economic sectors, such as Robotics, Manufacturing automation, Telecom, Oil & Gas, Utilities, Renewable Engineering and Research & Development.

Partners

GUC – Robotics and Autonomous Systems (RAS) Research Group, German University in Cairo was founded in 2007 to conduct multidisciplinary research and development activities in the area of robotics and autonomous systems.

ZfT – Center for Telematics (ZfT), Germany is a research center of excellence that combines advanced methods from telecommunications, automation and informatics to provide services at remote locations. The ZfT addresses advanced methods for tele-operations of equipment in the area of applied research.

ISTESHAAR – Isteshaar is a research-support company dedicated to providing engineering services in the area of sensor technologies.

Associate

The Executive Secretariat for the Demining and Development of the North West Coast of the Ministry of International Cooperation is responsible for the North West Coast Development and Mine Action Plan.

MineProbe Outcomes

- A detailed study about challenging aspects of the problem of landmine and UXOs contamination in Egypt, the socio-economic impact of the problem and existing and emerging technologies.
- An efficient vehicle locomotion system to endow UGVs with ability to move fluidly and efficiently in rough terrain of NWC.
- Teleoperated and autonomous control modes for the UGVs.
- A centimeter-level accuracy outdoor hybrid localization system for unmanned ground vehicles.
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Final Beneficiaries

- **Deminers**
- **Civilians**
- **Egyptian Government**
- **Society**
- **MENA Region and Southeastern Europe**

The developed system is of strategic importance to the Egyptian society and fits very well into the Egyptian government plan for the development of landmine contaminated areas. These contaminated areas in the north coast, Gulf of Suez and red sea coasts are now being reclaimed for economic development so mine clearance is becoming an urgent priority for the Egyptian government.

Front face of first Brochure

Backward face of first Brochure

Rollup banner posters used in the Final conference

Envelope Invitations for the final workshop

"دعوة حضور"

معالي سيادة اللواء / محمد سعيد العصار – وزير الدولة للإنتاج الحربي

تحيـــــة طيبـــــة وبعـــــــد،،،

نشكر سيادتكم على رعايتكم الدائمة للإبتكار والإبداع في مصر وإهتمامكم بالبحث العلمى فى مصر لمواجهة التحديات القومية ،وإنه ليسعدنا و يشرفنا نحن شركة اينوفيجن سيستمز دعوة سيادتكم لحضور المؤتمر الختامي للمشروع البحثى:

"منظومة إستشعار موزعة للإستطلاع ورسم خرائط الألغام الأرضية في مصر"

MINEPROBE: *A Distributed Mobile Sensor System for Minefield Reconnaissance & Mapping in Egypt*

الممول من قبل وزارة التعليم العالي والبحث العلمي والإتحاد الاوروبي من خلال برنامجRDI باشراف القوات المسلحة المصرية وذلك يوم الخميس الموافق 25 مايو 2017 الساعة الحادية عشر صباحا بفندق دوست ليك فيو بالتجمع الخامس.

وتفضلوا سيادتكم بقبول وافر الشكر و التقدير،،،

شركة اينوفيجن سيستمز

دكتور مهندس/ علاء خميس الباحث الرئيسى للمشروع

www.InnoVision.systems
www.mineprobe.org

The Final Workshop for

MineProbe: A Distributed Mobile Sensor System for Minefield Reconnaissance & Mapping in Egypt

Dusit Thani Lake View – New Cairo – Dusit Ballroom

Thursday, May 25th, 2017

Workshop Program

Time	Activity	
09:00am - 09:30am	Registration	
09:30am - 10:00am	Morning Coffee	
10:00am – 10:15am	Opening Session	
10:15am – 10:30am	Introduction : Ministry of Scientific Research – RDI programme	
10:30am – 10:45am	Keynote speech: H.E Ambassador ***Ivan Surkos*** Ambassador of EU to Egypt, Head of EU Delegation,	
10:45am – 11:00am	Keynote speech: H.E Dr. **Khaled Abd El-Ghaffar** - Minister of Higher Education and Scientific Research	
11:00am – 11:15am	MineProbe Sessions	Humanitarian demining: Facts, Socio-economic Impact and Technology Enablers (Dr. Alaa Khamis – Project PI)
11:15am – 11:35am		Robot Locomotion System for Rough Terrain (Eng. Mohammed Ashraf)
11:35am – 11:55am		Hybrid Global Localization for Unmanned Ground Vehicles (Eng. Mohammed Ashraf)
11:55am – 12:10pm	Coffee Break	
12:10pm – 12:30pm	MineProbe Sessions	Multimodal Landmine and UXO Detection System (Dr. Alaa Khamis – Project PI)
12:30pm – 12:50pm		Cooperative Mapping using Mobile Sweepers (Dr. Alaa Khamis – Project PI)
12:50pm – 01:00pm		Project Outcomes: A Summary
01:00pm – 02:00pm	Lunch Break	
02:00pm -02:20pm	Mine Risk Education and Victim Assistance in Egypt, MineTech Egypt – Mr. Ahmed Amer	
02:20pm – 03:20pm	Panel Discussion: Role of Technology in Humanitarian Demining in Developing Countries	
03:20pm – 04:00pm	Media Press Conference	

Workshop Agenda (A4)

2.7. Please list all contracts (works, supplies, services) above 10.000€ awarded for the implementation of the action since the last interim report if any or during the reporting period, giving for each contract the amount, the award procedure followed and the name of the contractor.

Tender was published at 15/09/2015 awarded by Consultix Company to supply technical items (Annex 4)

2.8. Describe if the Action will continue after the support from the European Union has ended. Are there any follow up activities envisaged? What will ensure the sustainability of the Action?

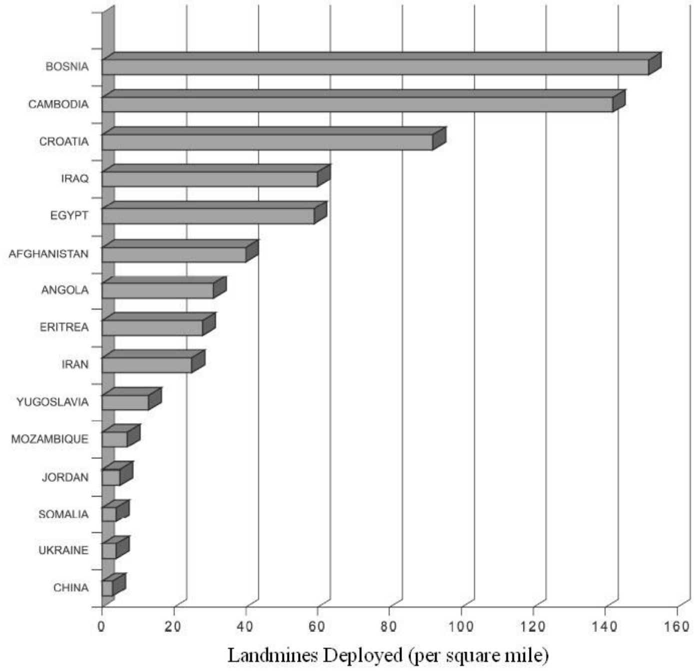
The main applicant is now establishing communications with the Egyptian army to start field trials on live contaminated arenas in the North-West coast. As the ministry of defence was monitoring the project as a whole during the implementation phase, and also attended the final conference and watched the full systems, they started to take some serious steps to start these trials the soonest possible.

On the other hands, we are providing different options for landmine detection including a complete mobile robot system like what came in the action, as well as a handheld sensory system for landmine detection based on the same technology developed in the action.

We are also targeting various other applications including autonomous robots, search & rescue robots that will be based on various know-how and technologies we used in the MineProbe

2.9. Explain how the Action has mainstreamed cross-cutting issues such as promotion of human rights[2], gender equality[3], democracy, good governance, children's rights and indigenous peoples, environmental sustainability[4] and combating HIV/AIDS (if there is a strong prevalence in the target country/region).[5]

According to the Domain review study generated from Work package 1 of the Action, Egypt has been listed as the country most contaminated by landmines in the world with an estimate of approximately 22.7 million landmines and other explosive remnants of war (ERW). This constitutes more than 20% of the total landmines worldwide. Egypt is also considered as the fifth country with the most antipersonnel landmine per square mile as illustrated below



The contaminated areas represent 22% of the total surface of Egypt. Development projects in these areas are significantly constrained by landmine and UXO contamination and the civilian casualty rate seems high in proportion to the populations in these areas. In Egypt, agriculture is one of the mainstays of the economy. Landmines are planted in fields, around wells, water sources, and hydroelectric installations, making these lands unusable or usable only at great risk. Egypt could increment its agricultural production if landmines were eliminated from the contaminated regions. The mines in a wide coastal strip, all the way to the Libyan border (and beyond), nearby coastal regions of Suez Canal Zone such as salt lakes and Red Sea coast prevent use of hundreds of thousands of sq. km. of agricultural land, prevent travel on thousands of km. of roads and deny access to potable water. These facts reflect the level of seriousness of landmines in Egypt. The contaminated areas in the North Coast, Gulf of Suez and Red Sea coasts are now being reclaimed for economic development so mine clearance is becoming an urgent priority for the Egyptian government.

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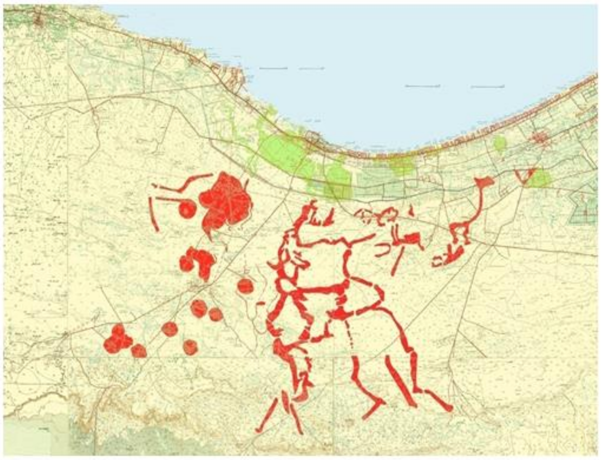
2 Including those of people with disabilities. For more information, see "Guidance note on disability and development" at http://ec.europa.eu/development/body/publications/docs/Disability_en.pdf

3 http://www.iiav.nl/epublications/2004/toolkit_on_mainstreaming_gender_equality.pdf

4 Guidelines for environmental integration are available at: http://www.environment-integration.eu/

5 To refer to EC Guidelines on gender equality, disabilities…



Contaminated Areas
Areas cleaned by the Army

It is estimated that there are 17.2 million of landmines and UXOs in the North West Coast (NWC) [2]. The contamination of the NWC of Egypt with explosive remnants of war dates back to the military events that took place in the Western Desert during WWII, mainly El Alamein battles (I & II) in 1942. Since then and for 70 years, Egyptians have been bearing the burden of conflicts they were not responsible for or party to. Yesterday's enemies are now allies and their past conflicts largely forgotten, buried in the ground along with the deadly mines and unexploded ordnance they left behind. The presence of these huge amounts of landmines & UXOs in the NWC constitutes a huge obstacle to the socio-economic development of the region - which is known for its rich natural resources - while representing a continuous threat to local inhabitants inhabiting the region. The existence of landmines and other ERW denies access to an area of approximately 22% of the Egyptian territory. Developing the NWC and its desert hinterland will undoubtedly reflect positively on the macroeconomic indicators of the country and contribute to improving the relationship between man and space in the country through attracting a sizable number of Egyptians currently living in the overcrowded Nile Valley and Delta region. The National Development Plan of Egypt identified immense resources to benefit local dwellers and the overall economic development of the region, including [4]:

500,000 acres of land good for agriculture and 3.5 million acres good for grazing;

70 million cubic meter of mineral resources;

1.8 billion barrel of oil and;

8.5 trillion Cubic meter of natural gas.

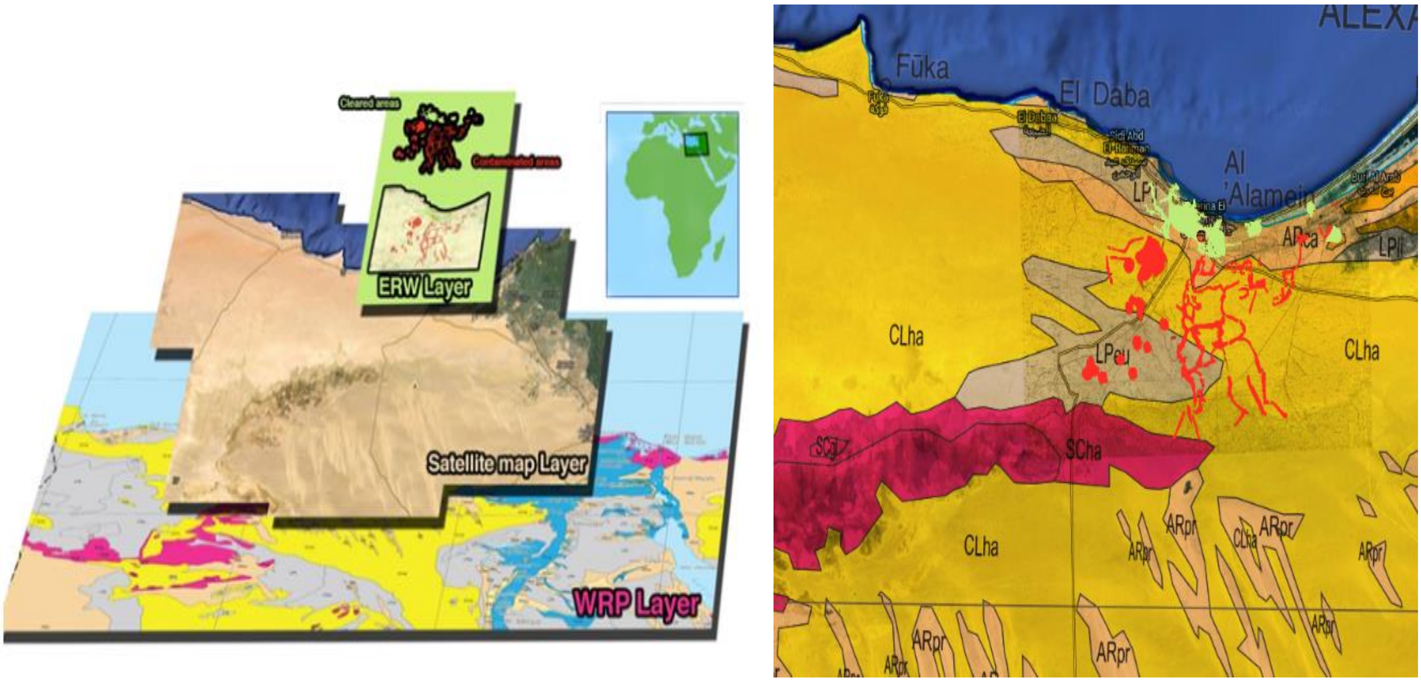
The data mentioned in the domain review was the main motivation for the MineProbe Action to take place. Also a comparison between MineProbe and various demining techniques is highlighted in this report (section 2.1)

As what came in this documentary https://youtu.be/pTKKTRUXF5o ,

2.10. What has your organisation/partner learned from the Action and how has this learning been utilised and disseminated?

As mentioned in the Action summary (section 2.1) , the below detailed points are the main projects outcomes that was developed and learned :

We currently have a very detailed study about the situation in Egypt, as well as we are monitoring the current situation in various other contaminated areas in the region including Syria, Iraq, and Yemen. In the same study we also managed to know exactly the types of soils in the north-west coast and used the soil data in designing an All-Terrain wheel.



7 soil types found in the North-West coast: *Loam, Sandy Loam, Sand, Dry Sand, Clay, Heavy Clay and Lean Clay*

Regarding the wheel design, we found that NASA has a simulation tool that models the Wheel-Soil interactions but it was strictly released only for funded projects supervised by NASA, so we have developed our own simulation tool for Terramechanics modeling to be used in studying the Wheel-Soil interaction (refer to Annex 5 Type of terrain in Egypt) . Since our mobile robot will negotiate rough terrain, it was necessary to build an in-house test rig for each wheel using a 2m length sand box.

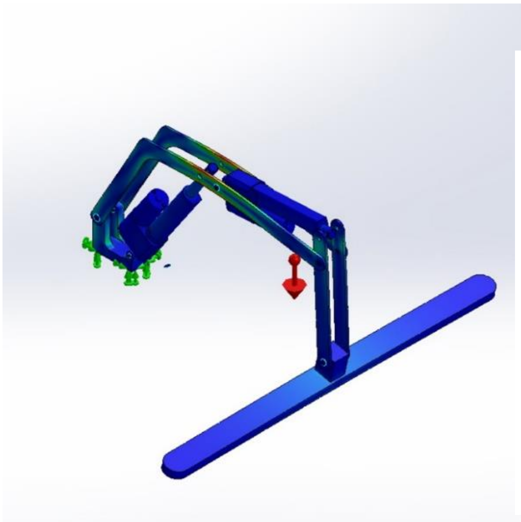
(refer to Annex 6 Design of Robot Wheels for Rough Terrain - A Multi-criteria Optimization Approach paper)

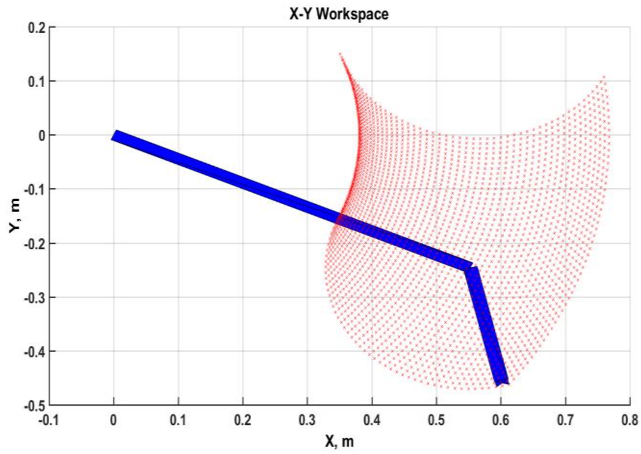
We are currently experienced in building an efficient communication infrastructure between various mobile robots moving in the field, and a control room for operations. In addition to a software safety layer that allows for safe operation in case a rover lost communication and to return home using the best and safest path recorded while scanning the contaminated area.

We achieved <10cm positioning accuracy for all rovers in the field, which means that a high accuracy digital map for landmines are automatically generated and can be visualized over various commercial maps like Google maps and openmaps.

The Novelty of the action lies mainly on developing a dual sensory system for landmine detection that uses different sensors models (Metal detector, and Ground penetrating radar) to provide better results than single sensor detection systems. The results showed a significant improvement in detection rates and reduced false alarms. We are currently working on additional features like shape classification of buried mines and linking shape patterns detected to a database where the sensory system will be able to retrieve the mine model used based in its's shape, reflected signal and metal content.

We are able now to design special and tailored light-weight robotic arms that can be mounted on mobile robots, cars, and moving vehicles or even a fixed base for materials handling in a lab (refer to Annex 7 Arm design).





3. Partners and other Co-operation

3.1. How do you assess the relationship between the formal partners of this Action (i.e. those partners which have signed a partnership statement)? Please provide specific information for each partner organisation.

Action applicant team was highly motivated and worked hard to get all the remaining work packages and tasks completed before the deadline in very professional, efficient and timely manner. The partners were collaborating according to the allocated tasks based on the project schedule. Partners were engaged in project bi-weekly meetings and workshops and they are in contact with the action applicant in a daily basis and with each other through the project web-based collaborative tool of the project (ASANA).

Applicant was the main responsible of WP-6, WP-7 and WP-8 conducted during this reporting period. The main role of ZfT is to evaluate the technical reports and the demos produced from the different work packages of the action. The main role of the GUC was in WP-8 during system integration and field trails.

3.2. Is the partnership to continue? If so, how? If not, why?

We are in contact with ZfT for future projects and funds under the Horizon2020 scheme. The GUC is cooperating very well with us in providing desert-like arena for further development and testing for new capabilities and features to be added to the Mineprobe distributed mobile sensory system.

3.3. How would you assess the relationship between your organisation and State authorities in the Action countries? How has this relationship affected the Action?

The state authorities were highly cooperative and supportive. The representative of Egyptian Armed Forces expressed his appreciation for the accomplishments of the project and mentioned the possibility of giving the MineProbe team access to a risky arena in NWC in order to test the developed system. He sees a great potential to use the developed system in the landmine detection missions in Egypt.

3.4. Where applicable, describe your relationship with any other organisations involved in implementing the Action:

- Associate(s) (if any)
- Sub-contractor(s) (if any)
- Final Beneficiaries and Target groups
- Other third parties involved (including other donors, other government agencies or local government units, NGOs, etc)

Not applicable.

3.5. Where applicable, outline any links and synergies you have developed with other actions.

Not applicable.

3.6. If your organisation has received previous EU grants in view of strengthening the same target group, in how far has this Action been able to build upon/complement the previous one(s)? (List all previous relevant EU grants).

Not applicable.

3.7. How do you evaluate co-operation with the services of the Contracting Authority?

4. Visibility

How is the visibility of the EU contribution being ensured in the Action?

The European Commission may wish to publicise the results of Actions. Do you have any objection to this report being published on the EuropeAid website? If so, please state your objections here.

Name of the contact person for the Action: ……………………………………………

Signature: ………………………………Location: ……………………………………

Date report due: ……………………..…Date report sent: ………………………………

Annex 1: Landmines and UXOs in NWC - A Domain Review
Annex 2: UGV Locomotion System for Rough Terrain
Annex 3: GPR and EMI Information Fusion Approach to Landmine Detection
Annex 4: Consultix Technical Offer
Annex 5: Types of Terrain in Egypt
Annex 6: Design of Robot Wheels for Rough Terrain - A Multi-criteria Optimization Approach
Annex 7: Arm_Design_v2

Annex 1

Landmines and UXOs in NWC: A Domain Review

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***Abstract*—This paper summarizes the results of a domain review conducted within MineProbe project to study the challenging aspects of the problem of landmine and UXOs contamination in Egypt, to survey the current solutions used to face this problem, to gather the fundamental requirements for the technology-based solutions and to assess the different technologies which may help to solve this serious problem. MineProbe: A Distributed Mobile Sensor System for Minefield Reconnaissance and Mapping in Egypt is an applied research project that aims at developing a novel minefield reconnaissance and mapping system in Egypt focusing on North West Coast (NWC) as location of the action. MineProbe system encompasses a number of spatially distributed unmanned vehicles equipped with different types of sensors to detect obstacles, landmines and Unexploded Ordnances (UXOs). This system provides a minefield map in which the locations of the detected landmines and UXOs are identified. This map can be used later by the Army engineers to destroy or deactivate the identified ordnances in the field.**

***Keywords*—humanitarin demining, landmines, UXOs, North West Coast, Socio-Economic Impact.**

I. INTRODUCTION

A landmine is the perfect soldier: Ever courageous, never sleeps, never misses [1]. The simplicity, versatility, high degree of reliability and cost-effectiveness of mines are major factors in explaining the widespread use of mines throughout the numerous countries that are now faced with dealing with the mine contamination problem. Conventional pressure-operated landmines can be broadly classified into anti-personnel (AP) mines and anti-vehicle or anti-tank (AT) mines according to target weight. The former are munitions designed to explode from the presence, proximity, or contact of a person while the later are munitions designed to explode from the presence, proximity, or contact of a vehicle as opposed to a person [2]. AT landmines cannot be exploded by persons unless that a person undertakes a deliberate act to move or dismantle the landmine. There are 2000 different types of mines around the world; among these, there are more than 650 different types of AP landmines. AT mines include, but are not limited to, blast mines, shaped charge/Misznay Schardin effect, full width mines, side attack mines, wide area mines. AP mines include fragmentation and stake mines, shaped charge mines, directional mines, blast mines, bounding mines, flame mines and chemical mines. Although these landmine designs are being constantly updated, the concept remains the same: the weapon is simple, versatile, and mass produced at low cost. According to Landmine and Cluster Munition Monitor report in 2014 [2], it is estimated that there are more than 110 million active mines scattered in 56 countries. Of these 56 affected states, 32 are party to the Mine Ban Treaty, a.k.a., Ottawa Treaty. However, this common estimate 110 million appears to be dramatically low compared to the number of AP mines stockpiled by many countries. Landmine Monitor estimates that there are more than 250 million AP mines stored in the arsenals of 108 countries. These mines must be destroyed before they have a chance to get into the ground. The largest stockpiles are held by China (110 million), Russia (60-70 million), Belarus (unknown, but likely tens of millions), and India (45 millions). The biggest current stockpiles of Ottawa treaty signatories belong to Ukraine, Italy, Sweden, Albania, Japan, United Kingdom, France, Spain, and Greece [3]. These landmines kill or maim more many people annually and cause serious injuries each year. Landmine injuries include blindness, burns, destroyed limbs and shrapnel wounds. Often the victim dies from the blast because they do not get to medical care in time. Moreover, landmines create millions of refugees or internally displaced people.

Significant percentage of landmine casualties is the result of AP landmines. These landmine sometimes are seen as a weapon of mass destruction in slow motion. According to a study on the impact of explosive remnants of war (ERW) in 60 states/regions in 2010, ERWs caused 4,191 causalities with landmines being the largest contributor (71%). Of the landmines causing injury or death, AP landmines had the highest percentage (34%), with victim-activated IEDs (18%), anti-vehicular landmines (10%), and landmines of “an unspecified type,” (9%) making up the rest [4]. In 2013, a total of 3,308 mine/ERW casualties were recorded by the Monitor. At least 1,065 people, of whom 46% are children, were killed and another 2,218 people were injured; for 25 casualties it was not known if the person survived [2]. In 2013, there were 1,112 child casualties in 39 states and three other areas from landmines, victim-activated improvised explosive devices (IEDs), cluster munition remnants, and other explosive remnants of war (ERW) [5]. In general, civilian casualties represent 79% of casualties where security forces casualties represent 18% and casualties between deminers are 3%. Between 1999 and 2013, the Monitor identified more than 1,500 deminers who were killed or injured while undertaking clearance operations to ensure the safety of the civilian population.

This paper summarizes the results of a domain review conducted within MineProbe project to study the challenging aspects of the problem of landmine and UXOs contamination in Egypt, to survey the current solutions used to face this problem, to gather the fundamental requirements for the technology-based solutions and to assess the different technologies which may help to solve this serious problem.

The remainder of the paper is organized as follows. Section 2 introduces humanitarian demining followed by describing the challenging aspects and the social-economic impact of the

problem of landmine and UXO contamination in NWC in Section 3. Current solutions are described in Section 4. An overview of MineProbe project is provided in Section 5. Finally concluding remarks are summarized in Section 6.

II. HUMANITARIAN DEMINING

Landmines are normally victim-operated instead of being specifically targeted, making them virtually unique among other weapon systems [6]. These landmines make no distinction between friendly or enemy, children or animals. The civilian-purpose demining or humanitarian demining aims at finding and removing abandoned landmines without any hazard to the environment. Humanitarian demining includes performing two main processes, namely, ERW localization and ERW disposal. The reconnaissance stage of the demining procedure aims at accurately localizing surface-laid and buried landmines and UXOs. This process is more challenging and the success of the second process depends mainly on the accurate localization of the ERW. If the landmines are accurately localized, they can be destroyed or deactivated.

Humanitarian demining is a costly process. Although mines cost between $3 and $30, but the cost of removing them is $300 to $1000 depending on the mine infected area and the number of false alarms. The cost of removing all existing mines would be $50- to $100-billion, which is beyond the capability of contaminated countries given the fact that most of these countries are poor developing countries. Until recently, about 100,000 mines were being removed, and about two million more were planted each year. This means that the annual rate of clearance is far slower than the rate of mine plantation. If demining efforts remain about the same as they are now, and no new mines are laid, it will still take 1100 years to get rid of all the world's active landmines. In many of the most affected areas of the world, agriculture is the mainstay of the economy. Landmines are planted in fields, forests, around wells, water sources, and hydroelectric installations, making these areas unusable, or usable only at great risk. Both Afghanistan and Cambodia could double their agricultural production if landmines were eliminated.

Many international initiatives have been established in order to ban anti-personnel mines and to provide awareness programs and to assist the victims. These invitees include, but are not limited to, International Campaign to Ban Landmines, Landmine and Cluster Munition Monitor, United Nations Mine Action, Ottawa Treaty, Swiss Foundation for Mine Action, Geneva Call, Canadian Landmine Foundation and International Coalition to Ban Uranium Weapons (ICBUW). International Campaign to Ban Landmines (ICBL) is a coalition of non-governmental organizations working for a world free of anti-personnel mines and cluster munitions, where mine and cluster munitions survivors see their rights respected and can lead fulfilling lives. Landmine and Cluster Munition Monitor is an initiative providing research and monitoring for the International Campaign to Ban Landmines (ICBL) and the Cluster Munition Coalition (CMC). The United Nations supports mine action in 40 countries and three territories. In some cases, UN services may be limited to one aspect of mine action—such as mine-risk education or victim assistance. Ottawa treaty, formally known as, convention on the prohibition of the use, stockpiling, production and transfer of anti-personnel mines and on their destruction [7] is an anti-personnel mine ban convention that aims at eliminating anti-personnel landmines around the world. Up to date, there are 162 States Parties to the treaty. Only 35 states are still remaining outside the Ottawa treaty. United States, Russia, China and Egypt are still non-signatories. There are 16 countries still considered as mine producers. Of these 16 countries, 8 are in Asia (Burma, China, India, North Korea, Pakistan, Singapore, and Vietnam), three in Europe (Russia Turkey, FR Yugoslavia), three in the Middle East (Egypt, Iran, Iraq), two are in the Americas (Cuba, US), and none are in Africa. Several of these 16 producers have not actually manufacturing AP mines in a number of years. They are still considered producers because they have refused to institute moratoria or make formal statements against production [3]. Total of 87 States Parties have completed the destruction of their stockpiled antipersonnel mines, destroying more than 47 million mines since 1999 [3]. A total of 75 States Parties have reported that they retain antipersonnel mines for training and research purposes. Six retain between5,000 and 7,000; 35 retain between 1,000 and 5,000; and, 31 retain less than1,000 [3]. The treaty calls on States Parties to provide assistance to mine-affected persons in their own country and to provide assistance to other countries in meeting their Mine Ban Treaty obligations. These facts may encourage the Egyptian government reconsider its stance which rejects joining the Ottawa Convention.

All of the above mentioned initiatives aim at banning landmines and providing risk education and victim assistance. Despite this global substantial efforts, the technology efficiently to detect and clear the world's landmine is still a long way off. The world is by no means united on the issue, and some of the Ottawa Treaty signatories are apparently not as committed to the cause as they would have us believe [6]. Very few initiatives have been undertaken or are currently undertaken to tackle the problem from technical points of view in terms of innovating detection and disposal techniques. While basic landmine detection and neutralizing theologies remain almost the same, landmine technology improved dramatically. Moreover, the humanitarian demining activities carried-out to remove landmines and unexploded ordnances from the vast contaminated areas are not on the same level of the problem. There is a serious need to innovative techniques that can provide efficient, reliable, adaptive and safe solution for the problem of the landmines and UXO contamination. This is the main objective of MineProbe project.

III. LANDMINES AND UXOS IN NORTH WEST COAST

The North West Coast of Egypt (NWC) extends from El-Alamain to El-Salloum in the west on the Egyptian-Libyan border and 30 Km deep from the Mediterranean coastline. The contamination of NWC with explosive remnants of war dates back to the military events that took place in the Western Desert during WWII, mainly El-Alamein 1st battle, "Alam Halfa" battle and EL-Alamein II battle in 1942. During World War II, extensive minefields known as Devil's gardens were planted in large areas that stretch from the Mediterranean coast to the Qattara Depression. Since then and for 70 years, Egyptians have been bearing the burden of conflicts they were

not responsible for or party to. Yesterday’s enemies are now allies and their past conflicts largely forgotten, buried in the ground along with the deadly landmines and unexploded ordnances they left behind [8].

A. Landmines and UXO in NWC

It is estimated that there are 17.2 million of landmines and UXOs in NWC [7]. However, analysis of accurate historic records shows that around 1.5 million mines were laid in the Western Dessert and that Egypt has only 2 million landmines, not 21 million landmines [6]. The overestimation is due to misclassifying all munitions as landmines. These landmines are spread in ten fields [9]. They are planted in these fields vary in type and size depending on the troops involved in action. Most of the landmines are buried in order to camouflage them from attacking troops. In most cases, mines are found very close to the surface (depth of 10cm). However, landmines can be deliberately buried deeply and in some other cases landmines can become buried deeper over time due to landslips or subsidence and other possible causes such as moving sands and the geographical effects that causes stones to rise in ploughed fields. In NWC area, the maximum depth considering environmental changes and moving sands in the area used to be 1 meter. Landmines can be scattered in the minefield according to a certain pattern or can be scattered randomly without any pattern. Patterns help in controlling the landmine distribution and in ensuring that the minefield achieves the correct balance between mine spacing and the number of rows in a given sized minefield. They can also help later in localizing the landmines if the maps are known. Keeley in [10] classified minefields into mixed minefields (AP+AT) and anti-personnel minefields. Most of the minefields in NWC are mixed minefields.

B. Socio-economic Impact

The presence of these huge amounts of landmines & UXOs in the NWC constitutes a huge obstacle to the socio-economic development of the region - which is known for its rich natural resources - while representing a continuous threat to local inhabitants inhabiting the region. Developing the NWC and its desert hinterland will undoubtedly reflect positively on the macroeconomic indicators of the country and contribute to improving the relationship between man and space in the country through attracting a sizable number of Egyptians currently living in the overcrowded Nile Valley and Delta region. The National Development Plan of Egypt identified immense resources to benefit local dwellers and the overall economic development of the region, including 500,000 acres of land good for agriculture and 3.5 million acres good for grazing; 70 million cubic meter of mineral resources; 1.8 billion barrel of oil and 8.5 trillion Cubic meter of natural gas [11]. Moreover, there is a high percentage of population under 15 years, and low percentage of working population in the productive age, compared with the national standards [12]. Developing this area will help in diverting the people’s movement away from the crowded urban centers such as Cairo and Alexandria.

C. NWC Terrain

A major challenging aspect of humanitarian demining in NWC is the rough terrain in the contaminated areas. The World Reference Base for Soil Resources (WRB) places all types of soil within thirty-two major soil groups with a series of uniquely defined qualifiers for specific soil characteristics [13]. In our study, in order to simplify the analysis, and since it is not intended for geological researches, a map with only three layers is constructed, each layer contain specific data set, in order to discover which types of soil we will face in the demining process of the contaminated areas in NWC. The three layers proposed in this study are described as follows:

- **Layer 1 – World Reference Base (WRB) soil types Layer:** In this layer, the Atlas of Africa is used to overlay the soil types over the map of Egypt.
- **Layer 2 – Satellite Global Map from Google maps:** This layer is used in order to map the terrain and known roads to the WRB layer.
- **Layer 3 – Explosive Remnants of War (ERW) in North-West Coast map:** In this layer, we overlaid the regions that are contaminated with Landmines and UXOs, and also the cleared areas by the Egyptian army.

According to the below overlaid map (Fig. 1), there are 4 main groups of soils in the North-West coast, and 7 soil types:

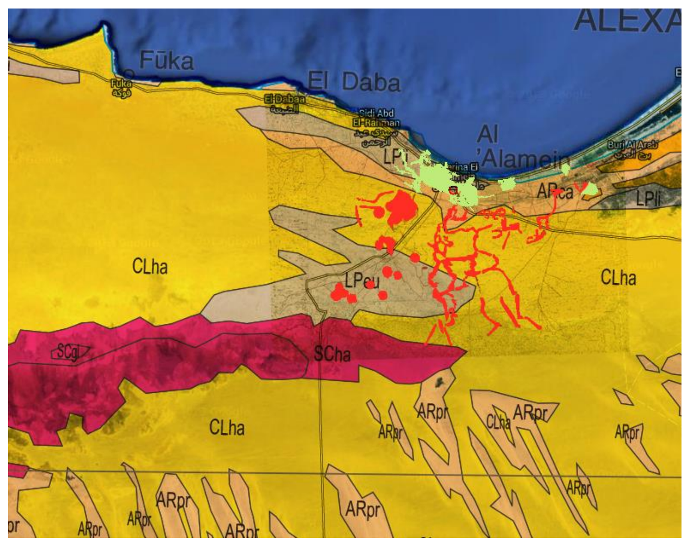

Figure 1. Overlaid WRP-Satellite map-ERW layers

- **Calcisols (from Latin calcarius, lime-rich):** this group comprises soil from drier regions with significant accumulation of calcium carbonate. The Calcisols are dominant in Africa covering 6% of the total area of the continent. They form through the leaching of carbonates from the upper part of the soil which precipitate when the subsoil becomes oversaturated, from carbonate rich water moving through the soil or by the evaporation of water which leaves behind dissolved carbonates. Precipitated calcium carbonate can fill the pores in the soil, thereby acting as a cementing agent, and can form a solid hard pan (calcrete) that is impenetrable to plant roots. In this NWC area, there is only one type of Calcisols soil: Haplic Calcisols (CLha), which is very acid with a clay-rich subsoil.
- **Arenosols:** easily erodable sandy soil with low water- and nutrient holding capacity (from Latin, arena, meaning

sand). Arenosols develop as a result of the in situ weathering of quartz-rich parent material or in recently deposited sands (e.g. dunes in deserts and beaches). Arenosols cover around 22% of Africa. In MineProbe's action location, there are two type of Arenosols soil in the North-West Coast: Calcaris Arenosols (ARca), which is sandy soil with notable levels of lime and Protic Arenosols (ARpr), which is sandy soil showing no horizon development.

- **Leptosols:** Leptosols (from Greek leptos, thin) are shallow soils over hard rock, very gravelly material or highly calcareous deposits and have a weak soil structure. Leptosols occur all over Africa, especially in mountainous and desert regions where hard rock is exposed or comes close to the surface and the physical disintegration of rocks due to freeze/thaw or heating/cooling cycles are the main soil-forming processes. In MineProbe's action location, there are two type of Leptosols soil in the North-West Coast: Lithic Leptosols (LPli), which is shallow soil over hard rock having continuous rock close to the surface and Eutric Leptosols (LPeu), which is shallow soil over hard rock, not acid.
- **Solonchaks:** Solonchaks (from Russian sol, Salt) are strongly saline with high concentrations of soluble salts. They are mostly associated with arid regions and with areas where saline groundwater comes close to the surface or where evapo-transpiration rates are considerably higher than precipitation, at least during a large part of the year. Salts dissolved in soil moisture remain behind after the evaporation of the water and accumulate on or just below the surface. Their characteristics and limitations to plant growth depend on the amount, depth and composition of the salts. In MineProbe's action location, there are two type of Solonchaks soil in the North-West Coast: Gleyic Solonchaks (SCgl), which is soil with accumulation of salt showing waterlogged conditions and Haplic Solonchaks (SCha), which is soil with accumulation of salt showing no major characteristics.

From the previous analysis of both NWC area terrain nature as well as the different types of soil in this region, it may be summarized that the terrain in the NWC area mainly consists of deep sandy loam, shallow sandy loam, rock outcrop, very shallow sandy loam, moderately deep sand, stony ridge and complex of shallow soil and sandy soil.

TABLE I. INVESTIGATED SOILS PARAMETERS VALUES

Soil Parameter	ρ	n	K_c	K_φ	c	φ	K	C_B	b	S	C_c	R_c	S_o
Loam	2.0	0.5	10.278	3.426	3.63	25	0.99	70	4000	0.3	0.9	0.114	0.5
Sandy Loam	-	0.2	7	3	0.2	38	-	-	-	-	-	-	-
Sand	1.9	0.55	11.42	13.133	1.45	28	0.984	560	4000	0.8	0.4	0.230	5.0
Dry Sand	-	1.1	0.1	3.9	0.15	28	-	-	-	-	-	-	-
Clay	2.0	0.18	19.985	17.130	5.076	18	0.984	7600	4000	0.2	1.0	0.078	0.0
Heavy Clay	-	0.11	7	10	3	6	-	-	-	-	-	-	-
Lean Clay	-	0.2	45	120	10	20	-	-	-	-	-	-	-

For each of the investigated soil types, the various parameters representing this soil type are identified and their relation and effect to the design process of the locomotion system are taken into consideration in MineProbe project. Table I summarized the identified parameters of the different soil types in NWC.

The selected parameters shown in Table 1 are soil density (ρ): The density of the soil under study measured in (g/cm3); exponent of sinkage (n); cohesive modulus of soil deformation (Kc) measured in (lb. /inn+1); frictional modulus of soil deformation (Kφ) measured in (lb. /inn+2); cohesion of soil (c) measured in (psi); angle of internal friction (φ) measured in (degrees); coefficient of slip (K) measured in (in); stiffness (CB) measured in (N/cm3); damping coefficient (b) measured in (Ns/m); slippery (S); compaction capacity (C_c); resistance correction (R_c) and shear offset (S_o).

Using these values, and the relationships that interrelates them, the appropriate locomotion system that is able to navigate within the target project's terrain on different soil types can be designed and implemented.

IV. CURRENT SOLUTIONS

The humanitarian demining activities carried-out to remove landmines and UXOs from the vast contaminated areas in Egypt are not on the same level of the problem [14]. However, the time spent by the Egyptian Army actively removing ERWs from the NWC gave it vast experience, very useful information and, generally, very good clues about mines and other ERWs, their kinds as well as the cost involved. So, now we know that 75% of WWII ERWs that await clearance are as illustrated in Fig. 2:

- Unexploded ordnance (UXOs), including 2,000-pound aircraft dropped bombs;
- different calibers of shells and mortars, rounds of machine guns and small weapons;
- 2.5% of the ERWs are anti-personnel mines and 22.5% are anti-vehicle, anti-tank mines.

The establishment of the Exec Sec in 2006 was a significant step forward in addressing the mine and ERW issue in Egypt and in addressing the economic marginalization of the NWC region. The Exec Sec is responsible for the following activities: coordinate among Egyptian stakeholders: governmental, private and belonging to the civil society; liaise with international development partners, including states, the UN, and other public and Non-Governmental Organizations; and receive and manage assistance earmarked to supporting the

objectives of the project. The Exec Sec has made significant progress during its short existence and always supports research and development initiatives to solve the problem of humanitarian demining in Egypt.

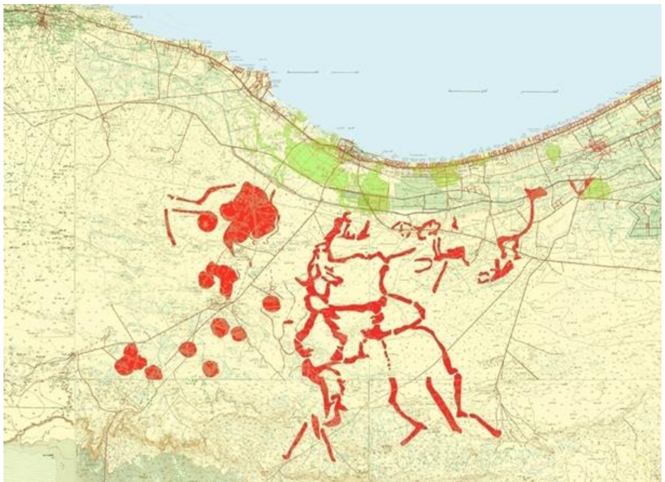

Figure 2. Contaminated and cleaned areas in NWC [8]

However, the conventional methods currently used in Egypt for landmine detection relay on close-in detection or close proximity detection where the deminer inspects the field from a close distance using hand-probing techniques such as metal detectors, magnetometers and ground penetrating radar, manned armoured vehicles or biological techniques. This incubates a high risk due to the potential detonation of possible landmine or UXO. For example, in the conventional mag-and-flag approach or Standard Operating Procedure (SOP) commonly used in NWC, human deminers use metal detectors to identify targets, which are then flagged for subsequent digging. These conventional approaches make the procedure of removing great numbers of landmines tedious, very slow, inefficient, dangerous and costly. The deminers sweep the area at least 3 times slowly and manually probe 2000 times per square meter to be certain that the area under scanning is clear from landmines. Deminers sometimes stay weeks and even months without finding a single landmine. A deminer is killed and two injured for every 5000 successfully removed landmines. In some missions only 12% of the target landmines are detected. Moreover, in manual probing no digital data are recorded and the success depends upon the deminer’s skill resulting in inconsistent results. Consequently, more efficient ways to detect and locate landmines and UXOs are needed.

V. MINEPROBE PROJECT

MineProbe [15] is a two-year applied research project that aims at developing a novel minefield reconnaissance and mapping system in Egypt. MineProbe system will encompass a number of spatially distributed unmanned vehicles equipped with different types of sensors to detect obstacles, landmines and UXOs. The system will provide a minefield map in which the locations of the detected landmines and UXOs are identified. This map can be used later by the Army engineers to destroy or deactivate the identified ordnances in the field.

The use of multiple mobile sweepers is intended to resolve the demining mission complexity, increase the minefield coverage, decrease the minefield scanning completion time and decrease the false alarm rate. The system will also provide increased reliability because having only one sweeper may work as a bottleneck for the whole system especially in critical times. However, when using multiple sweepers to perform a scanning task and one fails, other sweepers could still do the job. Multiple sweepers increase robustness through redundancy. Moreover, building several resource-bounded sweepers is much easier and sometimes more economical than building a single powerful sweeper for different complex missions such as minefield reconnaissance and mapping. The following subsections summarizes the objectives of the project and its final beneficiaries.

A. MineProbe Objectives

The main challenge of humanitarian demining mission is the lack of accurate minefield maps. For example, in Egypt available minefield maps are copies made by the British Defense Ministry from a few surviving historical documents and can only be relied upon with a limited level of confidence, because time and weather often shift the location of mines in the soil. Moreover, over time and due to landslips or subsidence and wind-blown sand, these landmines and UXOs became buried deeper. The lack of consistently accurate maps means that the exact location of minefields and placement of specific landmines are unavailable for deminers. The main objective of MineProbe project is to create accurate digital maps for the contaminated area using a set of teleoperated/ autonomous mobile unmanned sweepers. Providing these maps results in decreasing the injuries and save lives as first priority, speeding up the demining process reliably and safely, and allowing for using these lands for economic development of Egypt. The specific objectives of the project are as follows:

- Identify different challenging aspects of humanitarian demining in Egypt;
- Studying different candidate solutions in terms of locomotion mechanisms, types of sensors for obstacle detection, buried landmines and surface UXO detection, modes of operation and communication mechanisms among the mobile sweepers;
- Leveraging the experience acquired in this project to provide a blue print of a smart mobile sensor system able to provide a minefield map that contains the location of the detected landmines and UXOs;
- Migrate the developed system, sensors and sweeping and mapping approaches into off-the-shelf standardized minefield reconnaissance and mapping technology and
- Training of highly qualified personnel and generating knowledge of crucial importance, which may be a key for the daily struggle against landmines in Egypt and other contaminated countries.

B. Final Beneficiaries

The project is targeting different beneficiaries, shown as follows. The selection criteria of groups came from the major impact on the society of this group, and its contribution to country development:

- **Deminers:** The design of an accurate sensor may reduce the amount of time needed to determine whether a landmine exists, but does not increase the safety of the deminers. Since the safety issues during the eradication process are of great concern, the use and integration of cheap and simple mobile sweepers in MineProbe can provide a promising solution. MineProbe will replace the human deminers providing a safer, more accurate way for mine mapping.
- **Civilians:** Landmines are indiscriminate killers that target civilians long after a conflict has ended. The accurate maps created by MineProbe can be used to remove or deactivate the detected mines promoting a safe access for the civilian to the cleared lands. The proposed system will save lives, prevent lifetime disabilities and injuries which affect the person and the society as well.
- **Government:** Major effect of mines is to deny access to rich lands, and their resources. Besides this, the medical, social, economic, and environmental consequences are immense. The Government of the Arab Republic of Egypt represented by Executive Secretariat for the Demining and Development of the North West Coast is now recognizing that demining is no longer merely a humanitarian issue but rather also a major developmental concern. MineProbe will play a crucial role in solving the problem of landmines in Egypt promoting safe access to lands to develop new projects that contribute to country's development.
- **Society:** The proposed system is of strategic importance to the Egyptian society and fits very well into the Egyptian government plan for the development of landmine contaminated areas. Major effect of mines is to deny access to rich lands, and their resources. Besides this, the medical, social, economic, and environmental consequences are immense. These contaminated areas in the north coast, Gulf of Suez and red sea coasts are now being reclaimed for economic development so mine clearance is becoming an urgent priority for the Egyptian government. The technology and know-how to be developed in this project and the highly qualified trained personnel from this project will contribute to solve the problem of humanitarian demining in Egypt.
- **MENA Region and Southeastern Europe:** There are extensive landmines and UXOs contamination problems in most of the countries in MENA region and Southeastern Europe such as Libya, Sudan, Morocco, Algeria, Ethiopia, Eritrea, Yemen, Lebanon, Iraq, Iran, Kuwait, Bosnia and Herzegovina, Serbia, Bulgaria, Kosovo and Albania. These anticipated results of this project can be transferred to these countries through the establishment of regional cooperation crossing the cultural and political barriers among these countries.

VI. CONCLUSION

The problem of landmine and UXO contamination is a serious problem of political, economical, environmental and humanitarian dimensions. MineProbe aims at developing innovative techniques that can provide efficient, reliable, adaptive and safe solution for this problem. This paper described a number of challenging aspects related to the problem of landmines and UXOs contamination in the world and in Egypt. The report also discussed the scope of the problem in North West Coast (NWC) reviewing the history of the problem and identifying the availability of minefield maps, discussing the socio-economic impact of this problem in NWC and investigating the types and characteristics of NWC terrain that impact the locomotion system of the mobile sweepers to be designed in MineProbe project.

ACKNOWLEDGMENT

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Annex 2

UGV Locomotion System for Rough Terrain

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***Abstract*— This paper presents the design of a locomotion system for an unmanned ground vehicle to be used in minefield reconnaissance and mapping missions. The paper describes the analysis conducted to quantify the characteristics of rough terrain of the landmine contaminated area and its implications on selecting an efficient locomotion system. A comparative study based on 2-D and 3-D modeling is conducted between three 6-wheeled vehicles with articulated suspension. The optimal design is to be implemented within MineProbe project. MineProbe: A Distributed Mobile Sensor System for Minefield Reconnaissance and Mapping in Egypt is an applied research project that aims at developing a novel minefield reconnaissance and mapping system in Egypt focusing on North West Coast (NWC) of Egypt as location of the action.**

***Keywords*—Robot locomotion, wheeled locomotion, rough terrain, articulated suspension.**

I. Introduction

Abandoned landmines and other remnants of war used to be found in areas with variable terrain conditions. Unmanned ground vehicles are commonly used in minefield reconnaissance and mapping missions. The nature of vegetation and soil has direct impact on the performance of the humanitarian demining process. For example, thick vegetation or sandy or rocky terrain can hinders the deployment of detection/clearance vehicles. Soil variables also influence the detection of mines [1]. For example, hard, compacted soil or highly ferrous (iron) soil can hinder detection of mines or cause high false alarm rates. Careful attention should be paid to the design of efficient locomotion system for the unmanned ground vehicle that enable the vehicle to navigate through rough terrain and negotiate different types of obstacles and soils.

Vehicle locomotion is the study of how to design vehicle appendages and control mechanisms to allow robots to move fluidly and efficiently [2]. The problem of designing an efficient all-terrain locomotion system is inherently complex due to the large set of design variables to consider and a lack of information about the target terrain. This is especially the case for humanitarian demining missions. Different kinds of locomotion systems are available with different levels of complexities and motion fluidity and efficiency. Each locomotion system has its properties, complexity, limitations and cost.

This paper presents the design of a locomotion system for an unmanned ground vehicle to be used in minefield reconnaissance and mapping missions. The paper describes the analysis conducted to quantify the characteristics of rough terrain of the landmine contaminated area and its implications on selecting an efficient locomotion system. A comparative study based on 2-D and 3-D modeling is conducted between three 6-wheeled vehicles with articulated suspension.

The remainder of the paper is organized as follows. Section 2 describe the nature of terrain in NWC followed by describing different locomotion systems that can be used to endow the vehicle with the ability to negotiate this rough terrain in Section 3. Section 4 presents the three short-listed candidate mechanisms. 2D and 3D modeling and analysis of these mechanism are provided in Section 5 and 6 respectively. Finally, conclusion and future work are summarized in Section 7.

II. Unmanned Ground Vehicle Locomotion

A major challenging aspect of humanitarian demining in NWC is the rough terrain in the contaminated areas. The terrain in the NWC area mainly consists of deep sandy loam, shallow sandy loam, rock outcrop, very shallow sandy loam, moderately deep sand, stony ridge and complex of shallow soil and sandy soil [3]. For each of the investigated soil types, the various parameters representing this soil type are identified and their relation and effect to the design process of the locomotion system are taken into consideration in MineProbe project. The conducted study of the different terrain and soil types that exist within Egypt and more specifically the NWC area, serves mainly to the design and implementation of the appropriate locomotion system that can be used by the navigating vehicles. The following subsections describe different locomotion systems able to negotiate this rough terrain and highlight their relative pros and cons.

A. Locomotion Systems

Various locomotion systems exist for mobile robots, however when the problem addressed is that of a ground vehicle that navigates rough terrain, the problem becomes more challenging. The candidate locomotion systems are as follows:

- **Legged locomotion:** is characterized by a series of point contacts between the robot and the ground. As this locomotion system adopts a set of point contacts, thus the quality of the terrain type is not a main contributing factor as long as an appropriate value of ground clearance is being maintained. A walking robot is capable of crossing obstacles or a hole easily given that its reach exceeds the width of the hole. Legged locomotion system inhibits the ability to manipulate objects in their environment with great skill unlike other locomotion systems. Thus it may be concluded that the key advantages include adaptability and maneuverability in rough terrain. On the other hand, each leg of this mechanism include several degrees of freedom, and must be able to sustain the weight of the robot itself in both

lifting and lowering motion. The level to which this robot is capable of maneuver in its environment is highly related to the number of legs adopted. It may be concluded that adding degrees of freedom to the legs increase the overall maneuverability, however on the price of increased complexity, weight and power consumption. Thus it can be concluded that the main disadvantages of legged locomotion include power and complexity in both mechanical and control layers [2].

- **Wheeled locomotion:** can achieve very high efficiency with a simple mechanical implementation. It also achieves stability for the vehicle easily regardless of the number of the wheels used, as long as there are at least 3 wheels in contact with the ground at any time instant. When more than three wheels are used, a suspension system is required to allow all wheels to maintain ground contact when the robot encounters uneven terrain. This enables more focus on the problems of traction, control and maneuverability rather than balance issues [2].
- **Tracked slip/skid locomotion:** For wheeled locomotion systems, the assumption made that wheels don't slip neither skid is not practical for rough terrain environment. Another form of steering is to depend upon differential steering; spinning wheels on different side with different speeds and directions as well. This is mainly implemented in tracked locomotion system, like in tanks. Tanks have much more ground contact patches, this significantly improves their maneuverability in rough terrain rather than wheeled locomotion vehicles. However, this comes on the expense of adopting skidding motion directions in the mechanisms. One main disadvantage is related to slip/skid steering. The exact center of rotation of the vehicle is hard to predict and the exact change in position and orientation is also subject to variations depending on the ground friction. Therefore, dead reckoning on such robots is highly inaccurate. This is the trade-off that is made in return for extremely good maneuverability and traction over rough and loose terrain. Another main disadvantage is related to the power consumption of such locomotion system. In terms of power efficiency, this approach is reasonably efficient on loose terrain but extremely inefficient otherwise [2].
- **Hybrid locomotion:** Integrating the benefits of both legged and wheeled locomotion systems introduces the hybrid locomotion system. Where legged locomotion inhibits the capability to pass over obstacles and investigate rough terrain, and wheeled locomotion are highly efficient on hard surfaces, even at high speeds.

B. *A Qualitative Comparison*

The four locomotion systems discussed previously have been qualitatively evaluated in terms of some metrics in order to determine which is the most suitable locomotion system to be adopted in this study. In Table II, the relative performance of each of the locomotion systems against the selected performance metrics is shown.

TABLE I. LOCOMOTION SYSTEMS VS PERFORMANCE METRICS

Locomotion Type	Legged locomotion	Wheeled locomotion	Tracked locomotion	Hybrid locomotion
Mech. Complexity	High	Low	Medium	High
Control Complexity	Medium	Low	Low	High
Maneuve-rability	High	Low	Low	High
Power Efficiency	Medium	High	Low	Medium

Table III shows the relative performance of each of the locomotion system against the selected performance metrics.

TABLE II. LOCOMOTION SYSTEMS VS SOIL TYPES

Locomotion Type	Legged locomotion	Wheeled locomotion	Tracked locomotion	Hybrid locomotion
Loam	Low	Medium	Medium	Medium
Sandy Loam	Low	Medium	Medium	Medium
Sand	Low	Medium	Medium	Low
Dry Sand	Low	Low	Medium	Low
Clay	Low	Medium	Low	Low
Heavy Clay	Medium	Medium	Low	Medium
Lean Clay	Low	Medium	Low	Low

From the previous comparative table, it can be deduced that the most suitable type of locomotion system is the wheeled locomotion, as it provides a good compromise between simplicity in design and control as well as efficient power utilization. It also provides suitable traction capabilities for the different soil types that are investigated in the NWC.

III. CANDIDATE MECHANISMS

The following subsection describe three main articulated suspension mechanisms for ground vehicles.

A. *CRAB*

The CRAB concept follows the idea of using parallel kinematic elements like parallel bogies, which have excellent obstacle climbing capabilities. It has two parallel bogies on each side. They are connected at the bottom next to the axis of the middle wheel and at the top through an articulated rocker. A differential mechanism between the left and right suspension levels the pitch angle of the chassis. In this mechanism, the load is distributed evenly on all wheels. The front and rear bogies are identical. The rocker that connects both bogies is divided into two elements, with a rotational joint in the middle. Thus the system is fully symmetric.

B. *Rocker Boogie (RB)*

The RB configuration consists of a rocker and a bogie. They are linked by a pivot which allows the wheels to keep contact with the ground in uneven terrain. The wheel spacing is different on the various implementations of RB. If the distances are not equal, the position of the center of mass has to be chosen

accordingly to get equal load on all wheels. Left and right suspension are identical and linked by a differential.

C. RCL-E

RCL-E's suspension consists of three parallel bogies. There is one on each side at the front of the chassis on which the front and middle wheels are mounted. The third bogie is mounted at right angles to the other bogies at the rear of the chassis. It replaces a differential between the left and right suspension and serves as a leveling mechanism which keeps the mechanism simple. The CoM is situated right above the middle wheel, which creates equal loading on each wheel. The following two sections present the 2-D and 3-D modeling and analysis of these three mechanism.

IV. 2-D Modeling and Analysis

WM2D (Working Model 2D) is used as 2D simulation tool to model each locomotion system. WM2D was not directly used for the evaluation of the vehicles. It served as support and validation tool by providing vehicle states and slip values. The model to calculate the performance metric was implemented in Matlab. A very useful feature of WM2D is that it also comes with collision detection. Therefore, the simulation is ready to be run as soon as vehicle and terrain are modeled. The contacts are defined by coefficients of static and kinetic friction as well as an elasticity factor.

A. Up-and downhill Stability and Obstacle Climbing Analysis

Table I summarizes the up- and downhill stability and obstacle climbing analysis for the three locomotion models.

TABLE III. Locomotion Models

Model	Up- and downhill stability		Obstacle climbing analysis	
	θ-up	θ-down	μ_{needed}	T_{max} (N.m)
CRAB	50.9°	50.8°	**0.7**	5.06
RB	42°	**54°**	0.73	**4.344**
RCL-E	**53.7°**	35°	0.97	8.919

The angle θ represent the slope of the terrain. The maximal required torque T_{max} is an important factor as a higher torque will require a bigger motor, which adds weight to the vehicle and consumes more energy [4]. Thus, the model with the lowest required torque is best. μneeded is the minimum required friction coefficient for obstacle traversing. For a given state of the vehicle, which is determined by the shape of the terrain, the model that requires the least amount of friction to maintain equilibrium is the best performing model.

TABLE IV. Locomotion Models

Model	Up- and downhill stability		Obstacle climbing analysis	
	θ-up	θ-down	μ_{needed}	T_{max} (N.m)
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RB	42°	**54°**	0.73	**4.344**
RCL-E	**53.7°**	35°	0.97	8.919

These simulations provide useful information to eliminate bad performing configurations from the list of candidate systems at an early phase of development based on rather simple models. The stability calculations are probably too conservative because several real world factors can prevent tip over at the calculated angle. For example, the normal force on the middle wheel of the RB is the first which becomes zero. In order for the rover to lose stability, the middle wheel would need to lift off the ground which requires the bogie to rotate and the front wheel to roll backward. In reality, friction in the joints or cable harnesses could inhibit bogie rotation, and the controller would provide the motor with more current to keep the wheel from rolling. Therefore, the real vehicles are likely to show higher stability. The obstacle climbing analysis revealed that most of the asymmetric systems perform better than the average in one direction, but worse in the other one. CRAB I and CRAB II are symmetric systems and are ranked at the top of the list anyway. Since their performance is the same in both directions, they are more likely to be able to complete a planned path or back out in case of emergency than asymmetric configurations.

B. Sensitivity analysis – The effect of CoG on the Stability and the Obstacle climbing analysis

It was shown previously that the stability rankings between CRAB, RB, and RCL-E change when the CoG is moved to a higher Z position. Therefore, it is necessary to conduct a sensitivity analysis in order to investigate the impact of parameter modifications on the simulation results. This analysis was limited to the three main configurations CRAB, RB, and RCL-E. Fig. 1 depicts the results with respect to static stability. The actual values are represented by the dashed lines while the solid lines correspond to the linear regression. Five out of six curves show an almost identical decrease of stability with increasing CoG Z position of about 15° for the investigated Z range. In contrast, the downhill stability of RB varies by only 1°.

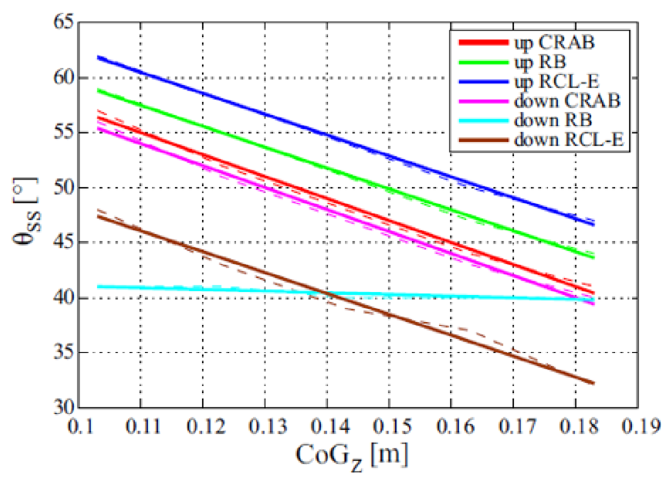


Figure 1. Sensitivity of static stability on Z position of CoG

The sensitivity of the friction requirement and the maximum torque is depicted in Fig. 2 and 3 respectively. As it was shown before, the performances of CRAB and RB are significantly better with respect to these metrics than the performance of RCL-E. The graphs also have in common that the slopes of RCL-E's curves are steeper than the slopes of the other curves.

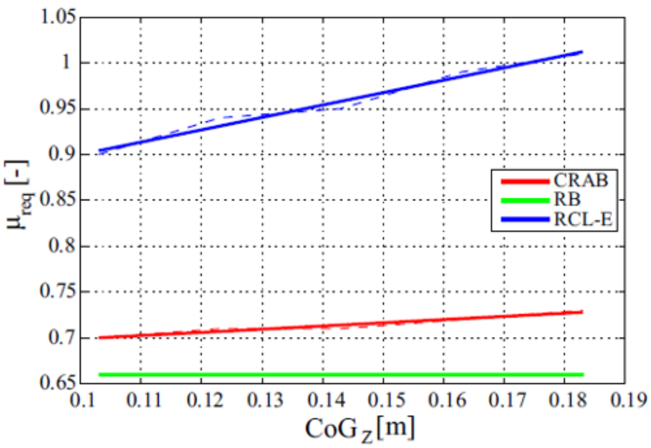


Figure 2. The sensitivity of the friction requirement on Z position of CoG

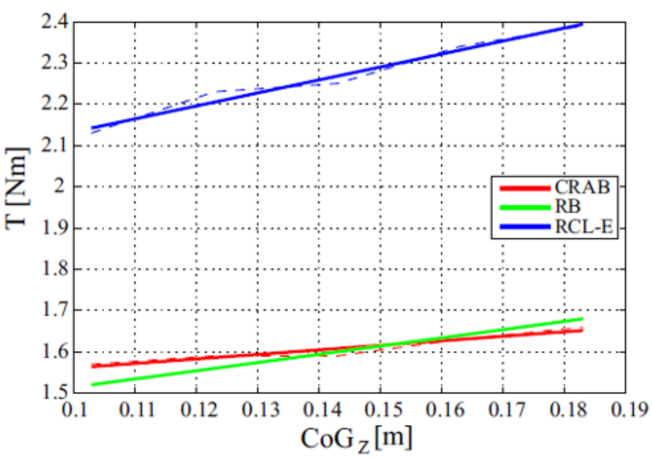


Figure 3. The sensitivity of the maxium torque on Z position of CoG

The sensitivity of the friction requirement expressed as variation over the investigated range is 5% (CRAB), 0% (RB), 10% (RCL-E), and of the maximum torque 5%, 10%, 10%.

The sensitivity of the static stability to modifications of the CoG depends strongly on the configuration which limits the validity of the performance rankings to the rover dimensions used in the comparison. The relative rankings of CRAB, RB, and RCL-E with respect to μ_{req} and the T_{max}, however, remain valid, the slightly different sensitivities of CRAB and RB regarding torque being negligible.

C. Concluding Remarks

Static analysis simulations provide useful information to eliminate bad performing configurations from the list of candidate systems at an early phase of development based on rather simple models. The stability calculations are probably too conservative because several real world factors can prevent tip over at the calculated angle. For example, the normal force on the middle wheel of the RB is the first which becomes zero. In order for the rover to lose stability, the middle wheel would need to lift off the ground which requires the bogie to rotate and the front wheel to roll backward. In reality, friction in the joints or cable harnesses could inhibit bogie rotation, and the controller would provide the motor with more current to keep the wheel from rolling. Therefore, the real rovers are likely to show higher stability. The obstacle climbing analysis revealed that most of the asymmetric systems perform better than the average in one direction, but worse in the other one. CRAB I and CRAB II are symmetric systems and are ranked at the top of the list anyway. Since their performance is the same in both directions, they are more likely to be able to complete a planned path or back out in case of emergency than asymmetric configurations.

A sensitivity analysis was conducted in order to investigate the impact of modifications to the CoG in Z direction on the simulation results. While the sensitivity of the stability metric depends on the configuration and therefore has an impact on the rankings, the relative performance with respect to obstacle climbing remains the same because the sensitivities of the investigated rovers are very similar to each other. The static analysis also has its limitations. The models are as simple as possible, thus, the results cannot be fully accurate. Consequently, small differences in simulation results cannot be taken for differences in real performance. However, the tendencies are correct and allow for selection of favorable systems.

V. Kinematic and Dynamic Analysis

The motion of mechanisms is analyzed by means of kinematic and dynamic models.

A. Kinematic Model

The kinematic model is explained using RB as an example.

- **First step – Simplification:** In a first step, the models were simplified (as indicated in Fig. 4) such that they maintained the kinematic properties while kinematic loops could be avoided.

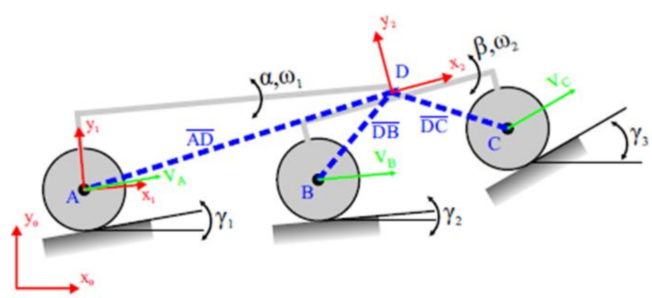


Figure 4. Simplified model

$$V_{D_A} = V_A + \omega_1 \times {}^0_1R(\alpha)\underline{AD}^1$$
$$V_{D_B} = V_B + \omega_2 \times {}^0_2R(\beta)\underline{DB}^2$$
$$V_{D_C} = V_C + \omega_2 \times {}^0_2R(\beta)\underline{DC}^2$$

Where
V_i : Velocity in i w.r.t inertial system,
ω_i : Rotational velocity of system i w.r.t inertial system,
${}^j_iR(\alpha)$: Transformation system j to i by rotation of angleα,
XY : Vector from X to Y expressed in coordinate system i.

B. Dynamic Model

Implemented in WM2D outputs the rover state in a randomly generated terrain to simulate a specific situation whereas the sine terrain is better suited for general performance analysis. Contrary to the static analysis the aim of the kinematic analysis is not to test extreme cases, but performance on realistic terrain geometry.

C. Metrics

The following metrics are used in the analysis:

- **Velocity constraint violation (VCV):** It is a measure for the risk of violation of kinematic constraints through deviation from the ideal velocity which leads to slip. In rough terrain, kinematic constraints require every wheel to rotate at an individual speed. Thus, deviation from the ideal velocity is more frequent and the slip level increases.

$$VCV = \frac{1}{m(m-1)} \sum_{j=1}^{m} \sum_{i=1}^{m-1} (\sigma v)_{i,j}$$

$$\sigma v = \left(\frac{1}{n} \sum_{i=1}^{n} (V_i - \bar{V})^2 \right)^{1/2}$$

$$V = \frac{v_{ideal}}{v}$$

- **Slip:** including slip ratio (S_r) and Accumulated slip (S_a).

$$S_r = \begin{cases} \frac{r\dot{\theta} - v}{r\dot{\theta}}\ ; & r\dot{\theta} > v(Acceleration) \\ \frac{r\dot{\theta} - v}{v} & r\dot{\theta} < v(Decceleration) \end{cases}$$

Where:
$\dot{\theta}$: Rotational wheel speed
v : Translational wheel speed
r : Wheel radius

$$S_a = \sum_{i=1}^{n} \left(\left| r\dot{\theta}_i - v_i \right| \right) \Delta t$$

Where:
n : Number of measurements
Δt : Sampling time

D. Simulation results

Simulation results with respect to metrics VCV and $S_a$on the sine terrain (2.43 m). all results are percentage of the rocker-bogie rover results.

TABLE V. SIMULATION RESULTS

Rover	VCV [-]	% of RB's VCV	S_a [m]	% of RB's S_a
CRAB	0.11	59	0.43	64
RB	0.18	100	0.67	100
RCL-E	**0.09**	**53**	**0.43**	**64**

The RCL-E has 47% less Velocity constraint violation than the RB and 6% less than the CRAB, while both the RCL-E and CRAB has 36% less accumulated slip (S_a) than the RB

E. Concluding Remarks

The performances of CRAB and RCL-E on the sine terrain are very similar and they are superior to the one of RB by about 40% and 33% with respect to V CV and Sa. Both types of simulation yielded valuable information about the assessed rovers and the metrics used for the analyses, which cover several aspects of mobility performance, helped detect significant differences between the evaluated systems. However, it is difficult to determine one single best rover because the rankings are different for all metrics. Therefore, application specific requirements are needed to distinguish the importance of individual locomotion capabilities. But the rankings also show that the analyses are complementary and contribute to a better overall understanding of the rovers' mobility performance.

The evaluation of such a big number of systems was only possible because the modeling work could be automated and simplified models could be utilized. Simplifications are always part of a trade-off which involves accuracy of results and complexity of models. Even though the focus is on simple models in this work, the results reveal interesting properties of design elements like the parallelogram bogie which is used on CRAB and RCL-E. While the parallelogram bogie was shown to have a strong, negative impact on the stability, it proofed to be a valuable element in the kinematic analysis. The bad obstacle climbing performance of RCL-E could be traced back to the fact that the parallelogram bogie distributes the load evenly to both wheels. Yet, the CRAB ranks among the best configurations, even though two parallelogram bogies are incorporated in its suspension. As for all simulations, a verification of the simulations by means of hardware tests is required to demonstrate the validity of the results.

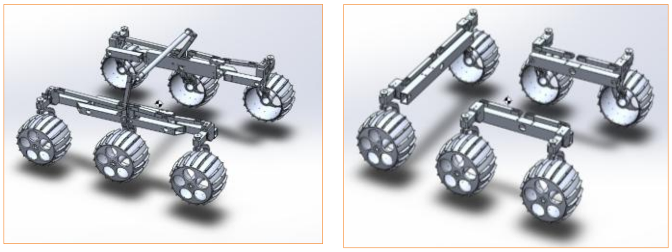
VI. 3-D MODELING AND ANALYSIS

As concluded from 2D modeling and analysis (Section V), CRAB II and RCLE outperform RB locomotion. A 3D modeling and analysis has been conducted in order to estimate manufacturing complexity and 3D motion performance. The design of the CRAB and RCL-E mechanisms are based on ExoMars project [5]. In this study, the following assumptions are considered:

- All the parts are made from the same material (6065 Aluminum);
- Wheel dimensions & distribution are the same;
- The payload structure has the same dimensions;
- The designs will be simulated on the same environment;
- The designs will be simulated with speed control method – required speed 15 RPM and
- The obstacles max height in the simulation will be 60% of the wheel diameter given that the wheel diameter is 20 cm.

As shown in Fig. 5 a) CRAB's suspension is based mainly on parallel bogies of which it has two on each side. They are connected at the bottom next to the axis of the middle wheel and at the top through an articulated rocker. A differential mechanism between the left and right suspension levels the pitch angle of the chassis. RCL-E's suspension (Fig. 5 b) consists of

three parallel bogies, one on each side at the front of the chassis on which the front and middle wheels are mounted and third bogie is mounted at right angles to the other bogies at the rear of the chassis. It replaces a differential between the left and right suspension and serves as a leveling mechanism which keeps the mechanism simple.



a) b)

Figure 5. a) CRAB Suspension and b) RCL-E Suspension

The RCLE mechanism is more simple to manufacture and maintain than the CRAB because of it minimized links and relations between bogies. Three scenarios with different obstacle distributions are set to test these two mechanisms. In the first scenario, the vehicle negotiates with no obstacles at all to calculate the lowest C.G. In the second scenario, the vehicle negotiates with the same obstacles at both sides and in the third scenario, one side of the vehicle negotiates with obstacle and the other side not. Fig. 6 shows the motion simulations (available on the YouTube channel of MineProbe project [6]).

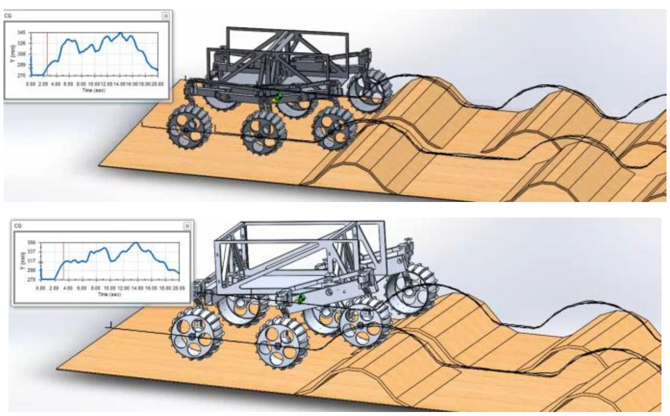


Figure 6. Motion Simulation for CRAB (up) and RCL-E (down) with C.G chart

Fig. 7 shows the average CG of each mechanism. As can be seen, the CRAB has lower C.G than the RCLE in most situations.

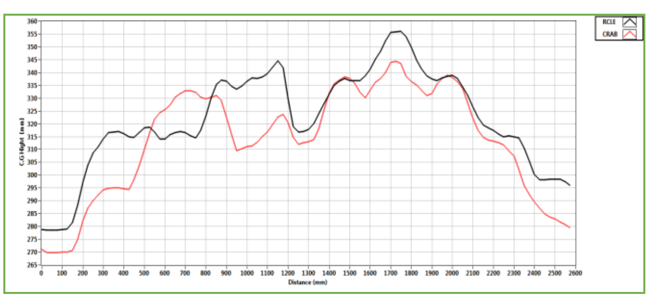


Figure 7. CRAB & RCLE CG Comparison

TABLE VI. CRAB VS RCL-E

Model	Complexity	Nominal C.G (mm)	Maximum C.G (mm)	Weight (Kg)
CRAB	Complex	**270**	**345**	**~ 23**
RCL-E	**Simple**	278	356	**~ 23**

The CRAB has slightly lower C.G than the RCLE in most cases (~20 mm max) but the RCL-E has very close performance and is more simple to manufacture.

VII. CONCLUSION

Unmanned ground vehicles must be endowed with the capability to adapt to uneven terrain and climb over obstacles in order to successfully accomplish tasks in rough terrains. The optimization of a particular design is a tedious process because the variables are coupled. As such, the optimization of one particular aspect of the design can have a negative influence on another. Moreover, at an early stage of the design phase there may be a large variety of candidate vehicle designs, and the selection of the most appropriate is usually not straight-forward. Thus, it is important to reduce this set in order to avoid a detailed evaluation of too many alternatives. Indeed, such a process would imply the design of the mechanical components of the chassis for complete simulation and testing, which is both costly and time consuming. In this paper, a comparative study based on 2-D and 3-D modeling has been conducted between three 6-wheeled vehicles with articulated suspension (CRAB, Rocker Boogie and RCL-E). The study concluded that RCL-E provides the best trade-off between performance and design complexity. The optimal design is to be implemented within MineProbe project that aims at developing a novel minefield reconnaissance and mapping system in Egypt focusing on North West Coast (NWC) of Egypt as location of the action.

VIII. ACKNOWLEDGMENTS

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Annex 3

GPR and EMI Information Fusion Approach to Landmine Detection

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***Abstract*— Accurately localizing surface-laid and buried landmine and unexploded ordnances is a challenging mission. Nowadays, there is no single sensor technology that has the capability to attain good levels of detection for the available landmines while having a low false alarm rate under various types of soil, different weather, different types of landmines and UXOs, natural and ground clutters, etc. Combing EMI and GPR data can provide more accurate estimate about the existence/absence of the landmine. This paper presents GPR and EMI probabilistic information fusion approach to landmine detection. Conducted experiments show that the dual sensor (fused EMI and GRP) outperforms individual EMI and GPR sensors in terms of variance, probability of detection and probability of false alarm.**

***Keywords*—EMI, GPR, Metal Detectors, Landmine Detection, Data Fusion, Bayesian Approach.**

I. INTRODUCTION

Civilian-purpose demining or humanitarian demining aims at finding and removing abandoned landmines without any hazard to the environment. This include performing two main processes, namely, ERW reconnaissance and ERW disposal. The reconnaissance stage of the demining procedure aims at accurately localizing surface-laid and buried landmine and unexploded ordnances. This process is more challenging and the success of the second process depends mainly on the accurate localization of the ERW. If the landmines are accurately localized, they can be destroyed or deactivated. This paper focuses on the problem of landmine reconnaissance. In conventional detection missions, the deminers used in the reconnaissance procedures are a major factor to the success of this stage. The time consumed by the deminers as well as their accuracy in the scanning procedures. Different types of sensors are nowadays available for landmine and UXOs detection. These sensors include, but are not limited to, Electromagnetic Induction Metal detectors (EMI), Ground-Penetrating Radar (GPR), infrared imaging, acoustics, acoustic imaging, Thermal Neutron Activation (TNA), photoacoustic spectroscopy, Nuclear Quadrupole Resonance (NQR), X-ray tomography, neutron backscattering, biosensors, etc.

MineProbe [1] is an applied research project that aims at developing a novel minefield reconnaissance and mapping system in Egypt focusing on North West Coast (NWC) as location of the action. MineProbe encompasses a number of spatially distributed unmanned ground/aerial vehicles equipped with different types of sensors to detect obstacles, mines and UXOs as illustrated below. The system provides a digital map for the minefield. In this minefield map, the exact locations of the detected surface-laid and buried landmine and UXOs will be identified. This mine map can be used later by the Army engineers to destroy or deactivate the identified ordnances in the field. In MineProbe, the complementary nature of the commonly used and reliable detection sensors is investigated to design and implement multimodal detection system. This system will be able to fuse data from detection sensors of different modalities in order to extending spatial/temporal coverage, enhancing reliability of measurements and decreasing the false alarm rate of the detection system and reducing data imperfection. This imperfection of data sources arises not only from the uncertainty and incompleteness of the observations, but also from the ambiguity and inconsistency caused by the limited and biased interpretation of those observations. Probabilistic, fuzzy and possibilistic models provide different frameworks that have been used to effectively represent and deal quantitatively with these imperfections [2].

This paper describes GPR and EMI probabilistic information fusion approach to landmine detection. The remainder of the paper is organized as follows. Section 2 introduces humanitarian demining followed by describing the challenging aspects and the social-economic impact of the problem of landmine and UXO contamination in NWC in Section 3. Current solutions are described in Section 4. An overview of MineProbe project is provided in Section 5. Finally concluding remarks are summarized in Section 6.

II. DATA FUSION APPROACH TO LANDMINE AND UXO DETECTION

Nowadays, there is no single sensor technology that has the capability to attain good levels of detection for the available landmines while having a low false alarm rate under various types of soil, different weather, different types of landmines and UXOs in NWC, natural and ground clutters, etc. EMI-based detector or metal detectors and GPR are commonly used sensors for landmine detection. Most of the used EMI detectors cannot distinguish a landmine from metallic debris, and in case of metal detectors, the extremely high false alarm rate, only one out of about one thousand alarms turned out to be a landmine. This results in a rather inefficient, costly and slow operation. GPR technology facilitates mine-detection operations by enabling the mapping of the sub-surface, as it can detect objects, volumes and areas that have different electromagnetic properties and can distinguishes metal fragments to from mines. Combing EMI and GPR can provide more accurate estimate about the existence/absence of the landmine. Multi-sensor fusion is a technology to enable combining information from several sources in order to form a unified picture. It is a

multidisciplinary research area borrowing ideas from many diverse fields such as signal processing, information theory, statistical estimation and inference, and artificial intelligence [2]. This is indeed reflected in the variety of the techniques reported in the literature [3].

Robustness, increased coverage, improved confidence, reduced uncertainty are a number of foreseen benefits of fusing data/information from multiple sources [4]. Multiple sources provide redundancy which, in turn, would enable the system to provide information in case of partial failure or data loss from one sensor. Spatial/geometrical and temporal coverage is enhanced as one sensor can look where other sensors cannot look and provide observations. Confidence is enhanced because measurements of one sensor are confirmed by the measurements of the other sensors. Multiple independent sources also reduce ambiguous interpretations and decreases uncertainty leading to improved probability of detection. However, if these multiple sources provide inconsistent data/information, catastrophic fusion may occur, and thus the estimated state obtained will be less accurate than if an individual source is used [5].

Many researchers proposed solutions to combine data from GPR and EMI sensors. A two modes (search and discrimination) landmine detection approach is described in [3]. A discrimination mode processing algorithms for metal detectors (MDs), or electromagnetic induction sensors (EMIs), ground-penetrating radars (GPRs), and their fusion are proposed. The performances of these proposed algorithms were examined on a dataset collected at a government test site. As described in [3], the probability of false alarm is reported as 70% at 100% probability of detection (Pd). Data fusion allows the system to achieve 100% Pd with only two false alarms. Comparing with the individual sensor results, the fusion significantly reduces the probability of false alarm.

A comparison between a feature-level and decision-level fusion methods for multisensory data was conducted in [4]. The authors used non-commensurate non-coincidently sampled data acquired by EMI, GPR, and IR sensors over a test field containing mine surrogates and both deliberate and unknown clutter for testing the fusion techniques. The results of their study showed that feature-level and soft-decision level fusion significant improvements in mine detection performance. The use of feature-level fusion provides a 40% reduction in the false alarm rate beyond the soft-decision fusion case and provides an explicit method for dealing with position errors, which is not available through the decision-level fusion algorithms. Although the computational of both feature-level fusion and decision-level fusion are approximately equal. There is, however, a small penalty for feature-level fusion since the classifier must be somewhat more complex to account for the greater number of inputs [4].

A fuzzy sensor fusion algorithm for GPR and MD sensors is described in [5]. The system's inputs are the feature extracted from both sensors (GPR, MD). A training data used in the pre-processing level for the fuzzy learning algorithm. Authors assumed that any tested object should satisfy 3 conditions to consider as a landmine, 1) position of features of both GPR and MD should be near from each other with a specific offset. The mine radius is used as the condition's offset. 2) The object should be detected a landmine suspect by a GPR. It means that GPR feature should be associated in the learnt fuzzy rule base. 3) The object should be detected as a land mine suspect by MD too. The MD feature should be associated within the fuzzy rule base. Their results show that the used fuzzy technique was able to automatically differentiate between a land mine and other objects which would minimize the false alarm rate significantly.

A two-level approach for modeling and fusion of anti-personnel mine detection sensors in terms of belief functions within the Dempster–Shafer framework is presented in [6]. The first level aims at identifying this content and at providing a classification into three classes. Depending on the metal content, the object is further analyzed at the second level toward deciding the final object identity. The results are obtained on real data. These data include IR, GPR and MD images, obtained on a sand lane containing 21 mines and 7 friendly objects. After the processing of each type of data, 42 regions are obtained, 28 corresponding to regions containing the actual objects, and 14 for which clutter produced alarms. This means that finally we have to recognize 21 mines and 21 false alarms. Results show that the fusion using this approach allows to improve the mine detection rate, while decreasing the false alarm rate [6].

III. PROPOSED APPROACH

the purpose of the proposed approach is to fused the information collected from the GPR and MD sensor. Figure 1 shows the main components of our approach. The following subsections describe these components.

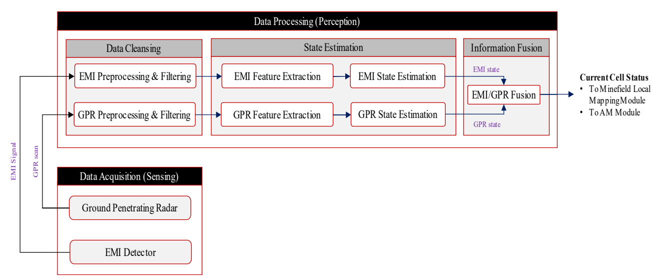


Figure 1. Proposed approach

A. GPR Pre-Processing & Filtering

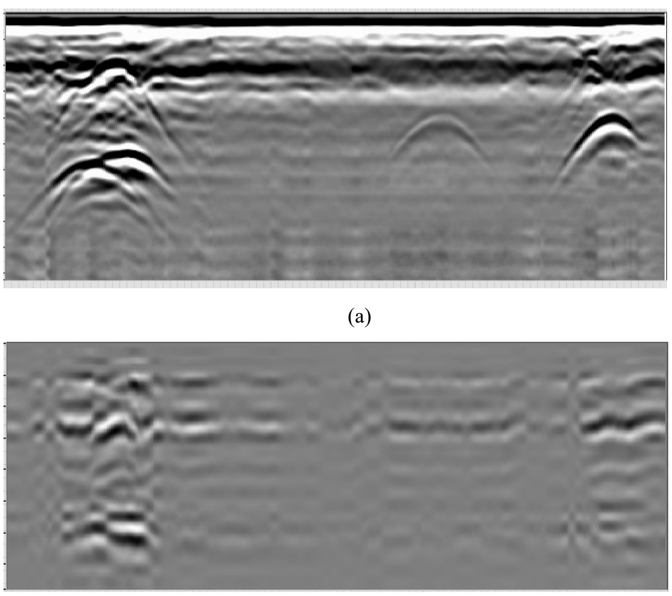
The pre-processing stage aims at reducing the ground effect and noise obtained by GPR sensor during the operation of landmines detection. the signal collected using GPR sensor is usually contaminated with ringing noises and ground surface reflections, therefore the filtering stage is an important part in our landmine detection approach. There are 3 main targets of pre-processing stage for the GPR sensor. Firstly, removing the ringing noise using Eigen image filtering method. Secondly, applying Principal Component Analysis (PCA) transformation and thirdly, estimating the 2D representation of the GPR output signal which will used in the fusion approach. Algorithm 1 shows the overall used approach for GPR pre-processing stage.

Algorithm 1: GPRFiltering(GPR_{3D})

Input : GPR data : GPR_{3D}
Output: Filtered version for GPR data :$FilteredGPR_{3D}$

Initialize:
Number of components to be kept : $N \leftarrow 3$
Eigen faces: $EF_{start} \leftarrow 1$, $EF_{end} \leftarrow 21$
begin
  % Filter Using Eigen Imaging
  Eigen Image Filtering:
  $FilteredGPR_{EigenImaging} \leftarrow$ filterGPRUsingEigenImages(GPR_{3D}, EF_{start}, EF_{end})
  % Filter Using Principle Component Analysis
  PCA Filtering:
  $FilteredGPR_{3D} \leftarrow$ filterGPRUsingPCA($FilteredGPR_{EigenImaging}$, N)
  return $FilteredGPR_{3D}$

- **Removing filtering noises using Eigen Images:** In this module Eigen images is responsible for removing the ringing noises from the GPR data. ringing noises are coherent noises appear in the GPR signal in horizontal and periodic events. Eigen images filtering method used in the proposed approach successfully remove these noises from the GPR collected data. The main idea behind Eigen filtering algorithm is to decompose the input matrix [D], mxn which m is the trace number and n is the data samples, into USVT where U and V are orthogonal matrices of $m \times m$ and $n \times n$, respectively and S is $m \times n$ diagonal matrix of which diagonal element, s_i, is called as a singular value of the matrix [D]. After getting U and V matrices, by selecting u_i and v_i vectors and multiply them together to get the Eigen image (Eigen face) E_i. we can get n number of Eigen images from the SVD matrix decomposer. By applying Band-pass filter on these Eigen images we can select some of them and apply weighted sum where s_i called the singular value of the Eigen image and it locates in the ith row of the diagonal matrix S. This process will produce a filtered version from the GPR input data. Figure 2(a) shows the input GPR data and Figure 2(b) shows the signal after applying Eigen images.



(a)

(b)

Figure 2. (a) GPR signal Data (b) GPR Filtered signal using Eigen filtering

- **Noise reduction using PCA:** The target of this module is to remove the coherent noise due to background responses, here we have used a method based on PCA statistical technique. PCA is used to reduce a large set of variables to a small set that still contains most of the information in the large set. PCA also can be used for removing uncorrelated noise and separating signal sources in transient electromagnetic (TEM). Algorithm 2 shows the details of noise reduction using the PCA technique.

Algorithm 2: FilterGPRUsingPCA(GPR,N)

Input : GPR data: GPR, Number of components to be kept: N
Output: $Filtered_{GPR}$

begin
  % Calculating PCA Scores and Eigen Vectors
  Principle Component Scores Matrix:
  $PCA_{Scores} \leftarrow$ calculateScoresMatrix(GPR)
  Principle Component Eigen Vectors Matrix:
  $PCA_{EigenVectors} \leftarrow$ calculateEigenVectors(GPR)
  Kept Principle Component Scores Matrix:
  $KeptPCA_{Scores} \leftarrow$ takeSubsetColumnsVectors(PCA_{Scores}, N)
  Kept Principle Component Eigen Vectors Matrix:
  $KeptPCA_{EigenVectors} \leftarrow$ takeSubsetColumnsVectors($PCA_{EigenVectors}$, N)
  % Reconstruct the Filtered Data
  Filtered GPR Data:
  $Filtered_{GPR} \leftarrow$ matrixMulitply($KeptPCA_{EigenVectors}$, $KeptPCA_{Scores}$)
  return $Filtered_{GPR}$

The algorithm used to calculate the uncorrelated multivariate (vector) time series which also called the principal component scores matrix [X]. Each row [x[i]] is the scores for one principal component. This matrix (mxn) is calculated from the correlation coefficient matrix of the input time series data [I] (mxn). Also the algorithm calculates the eigenvector (weight) matrix [V] where each column in it is one principle component. The equation used in this algorithm is where A is the m x m correlation matrix and variance of the scores for one principal component. By selecting f number of vectors from time series [X] and same number of vectors from corresponding eigenvector matrix and multiplying them together we will get a filtered version from the input data. Figure 2(a) shows the input data signal and Figure 2(b) shows the signal after applying the PCA noise reduction algorithm. we have chosen only the first 3 eigenvectors (f=3) in reconstructing the data signal.

- **Estimate representing 2D signal:** After getting the filtered signal from the GPR sensor, the probability of existing a target through the traces is estimated. The main target from this process is to construct the 2D signal of the GPR signal which will be used after that in the fusion technique. To estimate the target position, an edge detection of the filtered GPR signal is applied to extract the regions of interests in the signal and then applying energy projection method to generate the accumulated signatures in x-y plane where x represents the traces axes and y represents the amplitude of the signal in the trace. Figure 3 shows the output of applying multiscale edge detection algorithm.

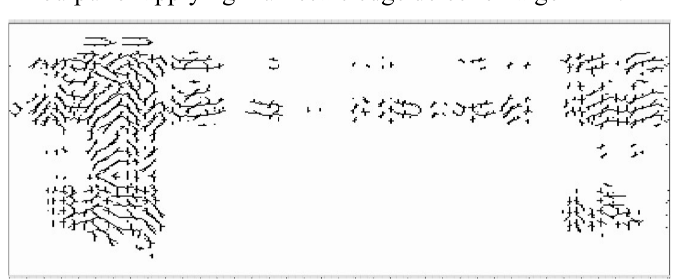


Figure 3. Multiscale edge detection result

Figure 4 shows the generated 2D signal which represent the GPR sensor output.

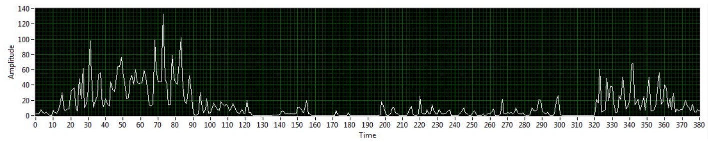


Figure 4. Generated 2D GPR signal

B. State Estimation

State estimation is popular problem related to variant robotics application. Robot has its own inner-state like its position and orientation and its outer-state which is the shape of the environment surrounding with it. For example, when the robot moves, the state estimator algorithm gives a prior estimation for the next position and orientation of the robots. There are different techniques for solving state estimation problem e.g. probabilistic techniques. Kalman filter is one of the widely used algorithms in solving state estimation problem.

State estimator is an important module in the proposed approach (Fig. 1) as it predicts the state of the area scanned by the mobile sweeper using the dual sensors. Kalman filter is used to predict the outer-state of the mobile sweeper in terms of existing of any surface-laid or buried landmine and/or UXO. Kalman filter inputs are the 2D generated GPR sensor and the metal detector sensor (EMI). It generates the new prior estimation about environment around the mobile sweeper. Figure 5 shows the estimated state for both (a) the GPR sensor and (b) the EMI sensor.

C. Information Fusion

Information fusion is the main component in the proposed approach. The definition of fusion is to get a most likely accurate result by fused two or more reading from different sources. Probabilistic approaches are the most popular approaches to data fusion [2]. The proposed fusion algorithm is based on a modified Bayesian approach [7,8]. This fusion algorithm relies on calculating the probability of the state given the sensor reading. It calculates the maximum difference between the reading and change the variance of the posterior estimation regarding this difference. Algorithm 3 shows the steps for the fusion algorithm used in our systems.

Algorithm 3: FuseGPRandEMIData(GPR,MD)

Input : GPR data GPR, Metal detector data MD
Output: $Fuzed_{variance}$, $Fused_{mean}$
Initialize:
Number of Traces : $M \leftarrow 3$
GPR Variance : $GPR_{variance} \leftarrow 0$
MD Variance : $GPR_{variance} \leftarrow 0$
GPR State Estimation : $State_{GPR} \leftarrow 0$
MD Variance : $State_{MD} \leftarrow 0$
GPR prior estimate error covariance : $P_{GPR}[i-1] \leftarrow 0$
MD prior estimate error covariance : $P_{MD}[i-1] \leftarrow 0$
GPR posteriori estimate error covariance : $P_{GPR}[i] \leftarrow 0$
MD posteriori estimate error covariance : $P_{MD}[i] \leftarrow 0$
GPR measurements : $Z_{GPR} \leftarrow 0$
MD measurements : $Z_{MD} \leftarrow 0$
begin
  for $i = 1$ *to* M **do**
    % GPR Variance
    Calculate: $GPR_{variance} \leftarrow$ calculateVarience(GPR[i])
    % MD Variance
    Calculate: $MD_{variance} \leftarrow$ calculateVarience(MD[i])
    % Pre-Filtering Using Kalman Filter
    Calculate: $(State_{GPR}[i]\ ,\ P_{GPR}[i]) \leftarrow$ kalmanFilter($State_{GPR}[i-1]$, $P_{GPR}[i-1]$, $Z_{GPR}[i]$)
    Calculate: $(State_{MD}[i]\ ,\ P_{MD}[i]) \leftarrow$ kalmanFilter($State_{MD}[i-1]$, $P_{MD}[i-1]$, $Z_{MD}[i]$)
    % Fusion based on Modified Bayesian as in Reference [7 and 8]
    Calculate: $(Fused_{mean}[i]\ ,\ Fused_{variance}[i]) \leftarrow$ fuseUsingModifiedBayesian($State_{GPR}$,$State_{MD}$, $GPR_{variance}$, $MD_{variance}$)
  return $Fuzed_{variance}$, $Fused_{mean}$

Figure 5 shows the output of the EMI state estimation, the GPR state estimation and fusion algorithm.

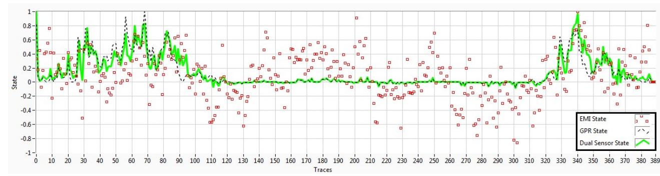


Figure 5. EMI state, GPR state and dual sensor state

As can be seen in Fig. 5, the resultant state from the fusion approach is not strongly influenced by the EMI state's noises. Also, the resulted state from the fusion is less sensitive for the false targets.

Figure 6 shows the variance of the 3 sensors (EMI, GPR and dual sensor) signals through the traces.

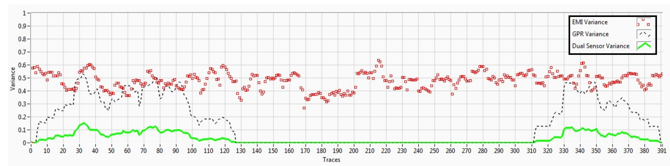


Figure 6. EMI, GPR and dual sensor variances

It can be seen that the state's variance of the dual sensor is always less than the state's variance of both GPR and EMI.

IV. Experimental Results and Discussion

A. Experiment Setup

The proposed approach is tested using a dataset that contain GPR sensor readings and systemized EMI data. The EMO signals are generated from GRP data to represent the output of the EMI. Figure 7 shows the color map of the GPR data matrix used to test our approach. it is a 3D data matrix. Trace dimension is calculated with trace number which represents the sampling time when the read has been taken. The depth is measured with nanoseconds which represents the time between sending the GPR waves and receiving them again. Pixel value in the color map represents the wave strength measured in the trace and the depth values.

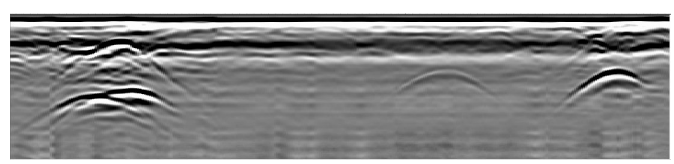


Figure 7. GPR signal data

Figure 8 shows the equivalent 2D signal generated using the preprocessing stage in our approach. The 2D signal is passed to the state estimation algorithm and fusion algorithm after that.

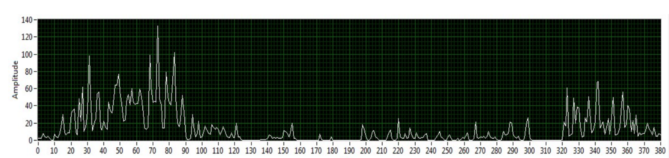


Figure 8. The Equivalent 2D GPR Signal

The algorithms are implemented using LabVIEW 2015 platform and ran on a Windows 64 bit-based machine with processor Intel(R) Core i5 2.66 GHz and RAM 4 GB. The horizontal axes representing the sampling time of the 2D GPR generated signal. The vertical axis represents the amplitude of the signal in this trace (which represents the probability of target existence). Figure 9 shows the equivalent EMI signal generated from the GPR signal. Inverse noises are added to the generated EMI signal to make it more realistic signal.

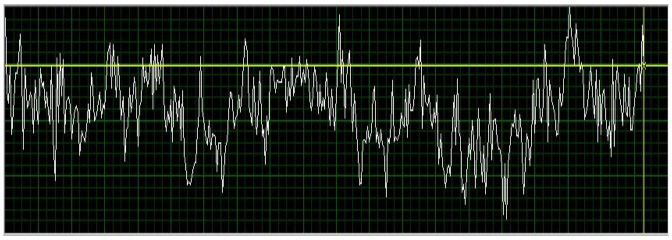


Figure 9. The Equivalent EMI Signal

Same as the 2D GPR signal, the horizontal axis represents the sampling time of the EMI generated signal and the vertical axis represents the amplitude of the signal.

B. *Results*

Three main evaluation metrics are used to evaluate the performance of the developed algorithm, which are variance, probability of detection and probability of false alarm. Table I summarizes the experimental results of EMI, GPR and dual-sensor (EMI with GPR) using a synthetic data set.

TABLE I. DETECTION SENSOR PERFORMANCE

Metrics/Sensor	EMI	GPR	Dual sensor
Variance	0.11	0.04	**0.00029**
Probability of detection (Pd)	50 %	100%	**100%**
Probability of false alarm (PFA)	80%	30%	**0%**

As can be seen, dual sensor outperforms both EMI and GPR sensors. According to the results our approach proves that information fusion for GPR and MD sensors is giving better results than each individual sensor. The probability of detection for the dual sensor, the output of the fusion, is almost the same with the GPR sensor. However, the probability of false alarms in dual sensor is much less than the individual sensors.

V. CONCLUSION

Multi-sensor data fusion is a key enabling technology in which redundant and complementary sensory data are combined in order to achieve higher quality information. Most of the commonly used EMI detectors cannot distinguish a landmine from metallic debris and suffer from extremely high false alarm rate. GPR technology facilitates mine-detection operations by enabling the mapping of the sub-surface, as it can detect objects, volumes and areas that have different electromagnetic properties and can distinguishes metal fragments to from mines. Combing EMI and GPR can provide more accurate estimate about the existence/absence of the landmine. In this paper, a novel approach to GPR-EMI fusion was presented. Experimental results show that the resultant dual sensors outperform the individual sensors in terms of variance, probability of detection and probability of false alarms.

As a future work, we are planning to implement the developed algorithm in a multimodal landmine and UXOs detection system mounted on unmanned ground vehicle as part of MineProbe project. This system will be able to fuse data from real EMI and GPR detection sensors in order to extending spatial/temporal coverage, reducing data imperfection, enhancing reliability of measurements and decreasing the false alarm rate of the detection system.

VI. ACKNOWLEDGMENTS

This research was carried out within the framework of “MineProbe: A Distributed Mobile Sensor System for Minefield Reconnaissance and Mapping in Egypt” project (EU-Egypt Innovation Fund - Grant Scheme 1 - EuropeAid/132-715/M/ACT/EG) funded by Research, Development and Innovation (RDI) Programme of Ministry of Higher Education and Scientific Research in Egypt and the European Union.

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TAX ID:	313/165/475
File:	5/00362/605/03/24
Trade Register:	30961

Annex 4

Consultix Technical Offer

MineProbe Technical Offer

October 12

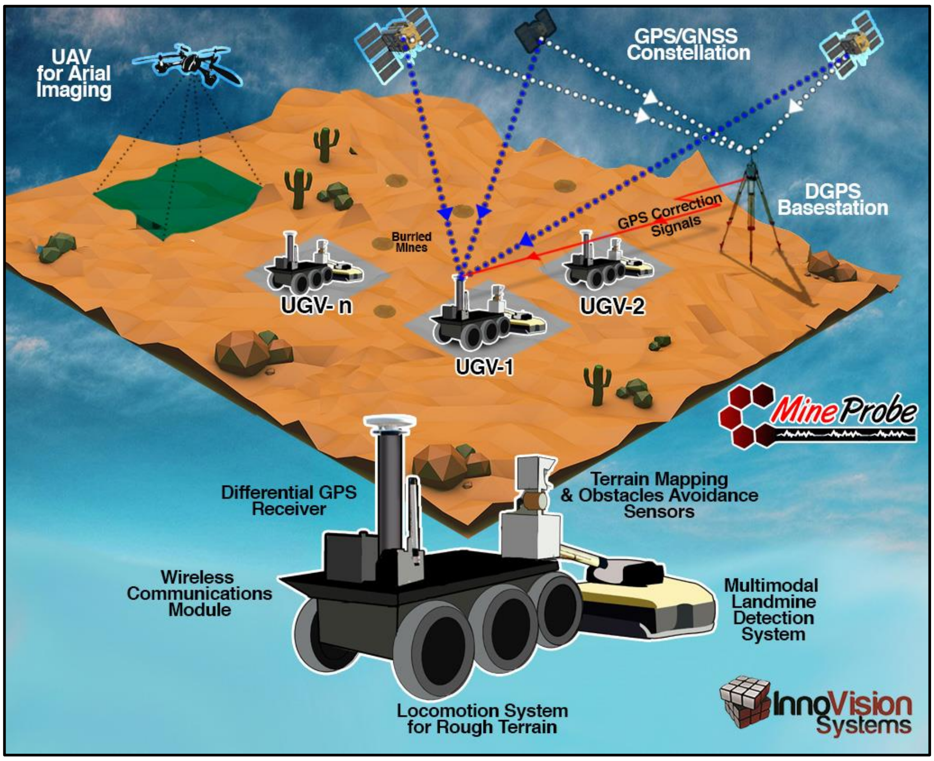
2015

InnoVision Systems

Building 162 front of AUC Gate 4, Mehwar Mubarak, El-Teseen St., 5th Settlement, 11835, New Cairo City, Cairo, Egypt.
Tel:+201005006238& +20229299708 www.consultix-egypt.com

1. Overview

Offering system components for Distributed Mobile Sensor System for Minefield Reconnaissance and Mapping in Egypt.



2.System Components

2.1. GPR

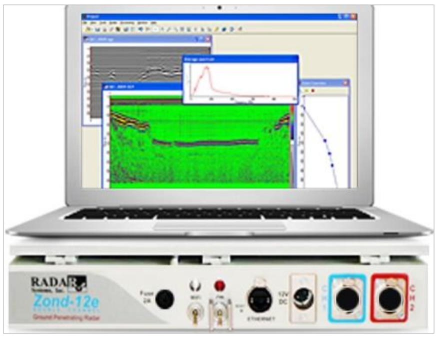
Description

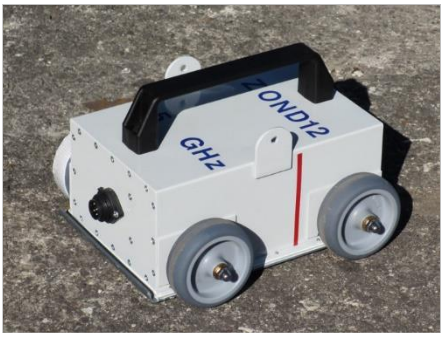
Zond-12e georadar is a portable digital subsurface sounding radar carried by a single operator. The unit is designed for solving a broad range of geotechnical, geological, environmental, engineering and other tasks wherever nondestructive operational environmental monitoring is needed. In the sounding process, the operator is getting real-time information as a radiolocation profile (sometimes also referred to as radargram) on a display. At the same time, data are recorded on a hard disc for further use (processing, printout, interpretation, etc.)

Zond-12e GPR system shielded surface coupled 1.5 GHz antenna unit is general purpose antenna with coupled transmitting and receiving antennas in strong housing with built-in odometer wheel, designed for shallow penetration depth, walls, floors, roads, bridges inspection and bricks, concrete profiling with 5-7 cm resolution* in concrete.

Specification

- Frequency: 1.5 GHz
- Resolution and depth: 0.05-0.07 x 1.5-2 m
- Weight: 3.2 Kg
- Data transmission: through Wi-Fi or Ethernet
- Real-time information on a display
- Recorded data on a hard disc for further processing





2.2. Bomb Locators (Metal Detector)

Description

Due to the simplicity in operation and handling the UPEX® 725 D has the advantage that it can be programmed to fade out interfering signals from non-cooperative soil, magnetic rocks and small pieces of scrap metal, which reduces the time factor significantly.

The UPEX®725 D is able to find previously masked UXO in an environment that is both geologically and artificially mineralized. Although designed for larger objects, on delay step 1 the UPEX®725 D is able to detect small objects as well.

Specification

- Anti-personal landmines detection range: 10 cm
- Anti-personal landmines detection range: 50 cm
- Output Signal: 0-5 V
- Weight: 2 Kg

2.3. RTK GPS

Description

AsteRx2eH PRO is a single-board, dual-frequency dual-antenna GPS/GLONASS heading receiver integrated into a waterproof aluminum housing, specially designed for complicated machine control, marine survey, photogrammetry and other multi-antenna applications.

Specification

- 272 hardware channels
- Up to 20 Hz data output rate
- Standalone Position Minimum Accuracy: 1.3 m Horizontal and 1.9m Vertical.
- RTK Position Minimum Accuracy: 0.6 cm + 0.5 ppm Horizontal and 1 cm + 1 ppm Vertical.
- Velocity Minimum Accuracy: 0.8 cm/sec Horizontal and 1.3 cm/sec Vertical.
- Heading Minimum Accuracy: 0.3° Heading and 0.6° Pitch/Roll
- Minimum Time to fix: <45 Sec Cold Start, <20 Sec Warm Start
- 4 High Speed RS-232 Communication Port, 1 Full Speed USB and 1 Ethernet Port
- Dual-frequency GPS/GLO/L-Band patch antenna with magnetic mount **for 3 Rovers**
- High Performance Multi-Frequency antenna supporting GPS/GLONASS/GALILEO/BEIDOU/L-Band **for 1 Base**
- Weight: 1 KG

2.4. RTK UHF Module

Description

SATELLINE-EASY is a state of the art transceiver radio modem providing a compact and flexible solution for many different long-range applications. It can be equipped with an LCD and push buttons for facilitating the configuration of the radio modem.

Specification

- Frequencies: 330-420MHz
- Channel Width: 12.5KHz / 20KHz / 25KHz
- Tuning Range: 90 MHz / 70 MHz
- Adjacent Channel Power: < -60 dBC
- Sensitivity BER < 10E-3 (FEC ON): -114 dBm @ 12.5 kHz
- Adjacent Channel Selectivity (EFC ON): > 47 db @ 12.5 kHz
- Data speed of radio interface: 19200 bps (25 kHz channel)
- Power Consumption save modes: < 1.2 W (Receive)
  < 7 w (Transmit 1 W)
  Sleep: 0.12 W / DTR: 10 mW
- Modulation: 4FSK, GMSK
- Operating Voltage: +3…+9 Vdc
- Carrier Power: 500 W
- Frequency Error Tolerance: < 1 kHz
- Spurious Emission: < -100 dBm (RX), < -80 dBm on 3rd harmonics @ 1215 – 1420 MHz (TX)

TAX ID:	313/165/475
File:	5/00362/605/03/24
Trade Register:	30961

2.5. Laser Range Finder

Description

The SICK LMS 100 is a new laser rangefinder with improved form-factor, power requirements. that is well-tailored to robotic applications in many ways and supports a 50 Hz scan rate over a 270° range, with 0.25° angular resolution. Their sensing range is 18 meters (at 10% reflectivity, max range of 20 meters), with an error of about 20mm. They require approximately 12 Watts of power, operating off on a 10.9-30.0VDC supply.

Specification

- Range: up to 18m
- Scanning angle: Max. 270°
- Angular resolution: 0.5°
- Scanning frequency: 50 Hz
- Accuracy: -/+ 50 mm
- Data interfaces Ethernet 100 Mbit TCP/IP, UDP; RS 232; CAN
- IP67 Protection
- Weight: 1.1 KG

2.6. Processing Unit

Description

CX5140 is Embedded PC from the CX5100 series based on the Intel® Atom™ multi-core processors. It differs from one another in housing width and CPU type. What is new is that the available Atom™ CPUs now also introduce genuine multi-core technology, extending up to quad-core, into the compact Embedded PC segment. Since the new devices are an extension of the existing CX5000 series, they are equipped with identical hardware interfaces. Two independent Gigabit-capable Ethernet interfaces as well as four USB 2.0 and one DVI-I interface are available. A multitude of further connection options and gateway functions is created by the multi-option interface, which can be pre-equipped ex-factory, as well as the I/O level, which can optionally consist of either E-Bus or K-Bus Terminals.

Specification

- Processor: Intel® Atom™ E3845, 1.91 GHz
- Number of Cores: 4
- Flash Memory: slot for CFast card (card not included), slot for microSD card
- Internal Main Memory: 4 GB DDR3 RAM (not expandable)
- Persistent memory: integrated 1-second UPS (1 MB on CFast card)
- Interfaces: 2 x RJ45, 10/100/1000 Mbit/s, DVI-I, 4 x USB 2.0, 1 x optional interface
- Diagnostics LED: 1 x power, 1 x TC status, 1 x flash access, 2 x bus status
- Clock: internal battery-backed clock for time and date (battery exchangeable)
- Operating system: Microsoft Windows Embedded Compact 7
- Control software: TwinCAT 3
- I/O connection: E-bus or K-bus, automatic recognition
- Power supply: 24 V DC (-15 %/+20 %)
- Current supply E-bus/K-bus: 2 A
- Max. power loss: 12 W (including the system interfaces)
- Dimensions (W x H x D): 142 mm x 100 mm x 92 mm
- Weight: approx. 960 g
- Operating/storage temperature: -25…+60 °C/-40…+85 °C
- Relative humidity: 95 %, no condensation
- Vibration/shock resistance: conforms to EN 60068-2-6/EN 60068-2-27
- EMC immunity/emission: conforms to EN 61000-6-2/EN 61000-6-4
- Protection class: IP 20
- Approvals: CE, UL, Ex, IECEx

Building 162 front of AUC Gate 4, Mehwar Mubarak, El-Teseen St., 5th Settlement, 11835, New Cairo City, Cairo, Egypt.

Tel:+201005006238& +20229299708 www.consultix-egypt.com

2.7.Omni Camera

Description

Grundig's extensive, new IP CCTV surveillance range offers an outstanding video security solution and is designed to meet every current surveillance requirement. Grundig has embraced the latest IP technology to create a range with impressive functionality and quality.
The new Grundig IP cameras are designed to suit every environment, however hostile or challenging. The new IP camera range includes PTZ and vandal-resistant domes for internal and external applications, traditional box cameras and specialist designs for specific application requirements. Further practical installation features include weather-resistance, a variety of mounting methods and comprehensive integration and compatibility.
Each camera offers advanced specifications, making effective use of the latest IP CCTV technologies. These include high resolutions providing clear images for detailed identification and evidential purposes a variety of exposure methods and encrypted recording directly onto a SD card. Intelligent features include privacy zones for non-invasive surveillance and legal compliance intelligent alerts to operators and system management tools using motion detection and other alarm triggers.
Each camera comes with full ONVIF support to ensure full integration and future-proofing.
German video security excellence - by GRUNDIG.

Specification

- 360° field of view
- 5 Megapixels CMOS, Colour/B&W Camera
- IR LEDs integrated
- ONVIF Profile S compliant for maximum compatibility with VMS
- H.264 & MJPEG compression modes (max. 30/25 fps)
- SDHC memory card slot for alarm and schedule image recording

2.8. UGV

Description

Unmanned Ground Vehicle for rough terrain with 2 degree of freedom robotic arm apple to carry the system payload of around 14 Kg.

Specification

- Locomotion System designed for rough Terrain
- Obstacles size range: 15-20cm height
- 2DOF Arm that can hold a max. of 4KG payload
- Number of wheels: 6
- Wheel Diameter: 30 cm
- Wheel Thickness: 6 cm
- Arm Motors torque: 40 N.m
- Wheels Motors torque: 30 N.m
- Motors peak current: 30 A
- Battery Voltage: 24V
- Battery Capacity: 40 Ah
- Vehicle Payload: ~ 11 Kg
- Arm Payload: ~ 4 Kg
- Vehicle Weight: ~ 32 Kg
- Total Weight: 47 Kg

2.9. UAV

Description

The Phantom 3 Advanced carries a fully stabilized 3-axis 1080p full HD video camera for smooth, crisp videos and still photos. The Phantom 3 Advanced includes an integrated array of optical and ultrasonic sensors call Vision Positioning that allows you to fly precisely indoors without a GPS signal. Including GPS navigation with auto takeoffs and auto landings, intelligent high power flight battery, a built-in safety database of no fly zones, and a powerful mobile app for your iOS or Android device.

Specification

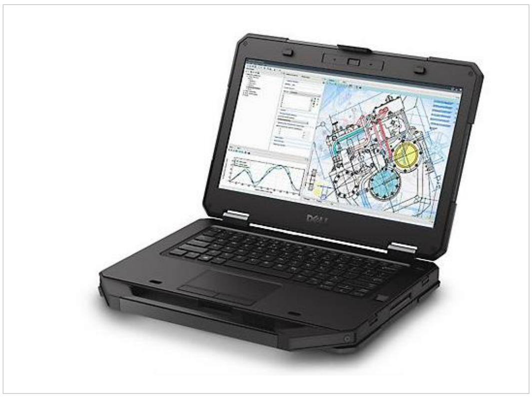
- Easy to Fly, Intelligent Flight System
- Integrated 3-Axis Stabilization Gimbal
- Dedicated Remote Controller
- Camera: Sony EXMOR 1/2.3” Effective pixels: 12.4 M
- Image Resolution: 4000 x 3000
- Field of View: 94°
- ISO Range: 100-3200 (video) 100-1600 (photo)
- Flight Time: Max 23 min
- Transmutation distance: 2000 m
- Battery Capacity: 4480 mAh
- Media Support:
  - Micro SD
  - FAT32/exFAT
  - Photo: JPEG, DNG
  - Video: MP4, MOV (MPEG-4 AVC/H.264)
- Flight Capabilities:
  - Control the camera
  - Gather flight data
  - Inertial Guidance System
  - Flight Modes
  - Emergency Return to Home
- Operating System:
  - iOS: This app is optimized for iPhone 5s, iPhone 6, and iPhone 6 Plus
  - Android: Samsung S6, Samsung S5, Samsung NOTE4, Samsung NOTE3, Google Nexus 9, Google Nexus 7 II, Ascend Mate7, SONY Z3 EXPERIA
- Voltage: 15.2 V
- Weight: 1.28 Kg
- Operating Temperature: 0°C to 40°C

2.10. Ruggedized Laptop

Description

Best-in-class rugged performance and proven enterprise-class security and manageability, the Latitude 14 Rugged notebook powered by Intel® enables you to push your limits and deliver in almost any harsh environment. Featuring heavy-duty components borrowed from our flagship Rugged Extreme, you can trust these notebooks can withstand shocks, drops and vibration.

Specification



- 4th gen Intel® Core™ i7-4650U Processor (3.3 GHz, 4M Cache)
- Windows 7 Professional x64 bit
- 8GB (1x8GB) 1600MHz DDR3L Memory
- 256GB Mobility Solid State Drive
- Intel® Dual Band Wireless-AC 7260 802.11AC Wi-Fi + BT 4.0 LE Wireless Card
- 14.0 HD (1366x768)
- UMA Video Card
- 6-cell (58Wh) Battery
- Ports: USB 3.0 (2), USB 2.0 (2), native RS-232 serial ports (2), RJ-45 gigabit Ethernet network connectors (2), stereo headphone/microphone combo jack, optional pogo-pin docking connector, VGA, HDMI

2.11. Standard Laptop

Description

Beautifully designed, thin and light Ultrabook™ that features a 14" display and Intel Core i5 Processor.

Specification

- 4th gen Intel® i5-5200U
- Windows 7 Professional x64 bit
- 8GB (1x8GB) 1600MHz DDR3L Memory
- 256GB Mobility Solid State Drive
- Dell Wireless™ 1560 (802.11ac 2x2, WiFi & BT)
- 14.0 HD (1366x768)
- UMA Video Card
- 4-cell (54Whr) Battery
- Ports: 3 USB 3.0, HDMI, Network connector (RJ-45), SIM card slot

RADAR Systems, Inc.

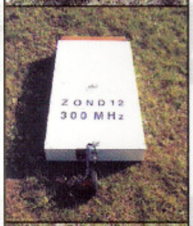
Ground Penetrating Radars

The best data quality at the best price!

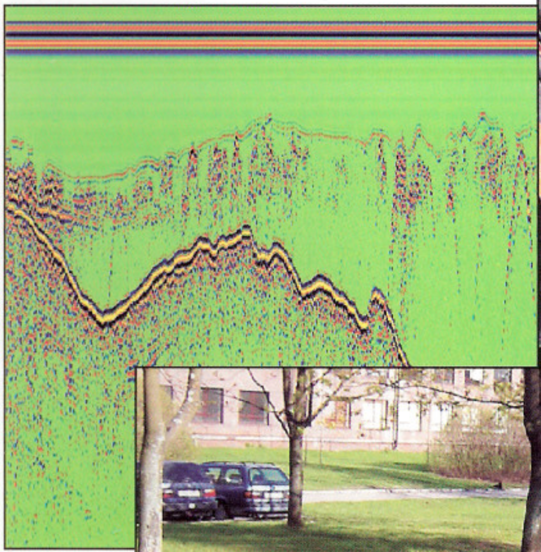
ZOND SYSTEM 12e

GROUND PENETRATING RADAR

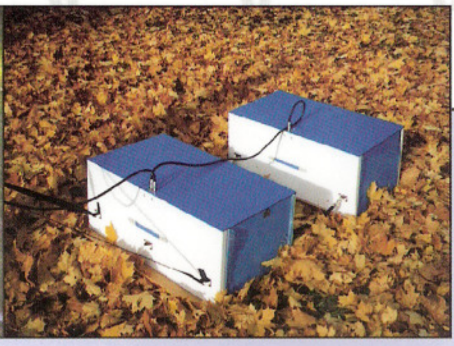










Web: http://www.radsys.lv
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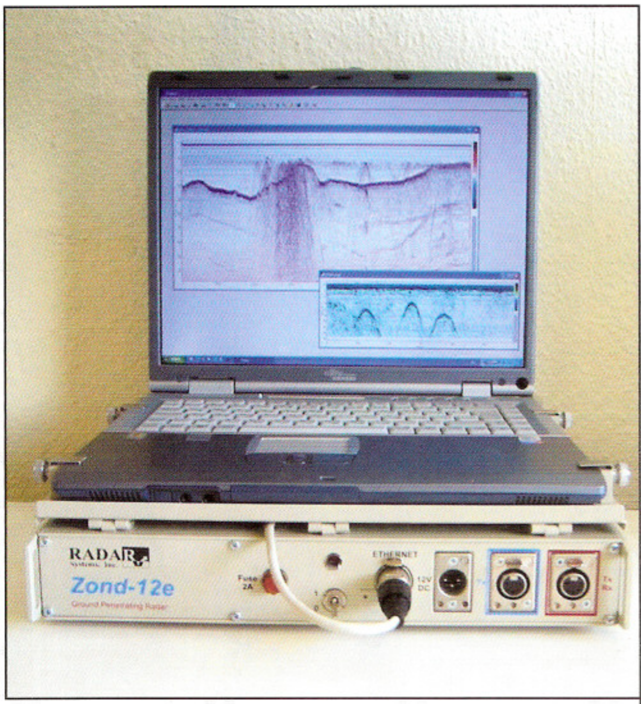
RADAR Systems, Inc. Ground Penetrating Radars

Zond-12e

General Purpose Pulse GPR

SINGLE OR DOUBLE CHANNEL CONTROL UNITS



SYSTEM ADVANTAGES:

TIME RANGE: user selected from 1 ns to 2000 ns with 1 ns step

SCAN RATE: 80 scans per second for DOUBLE CHANNEL, 56 scans per second for SINGLE CHANNEL

RESOLUTION: 16 bit

GAIN: up to 10 points digital function

DATA TRANSFER: through Ethernet

DATA ACQUISITION: in original shape

DATA OUTPUT: colored

ACCESSORIES:

Battery 12 V @ 3.2 A*h, Shoulder bag, Charger, Power cable, 3 & 20 m antenna cables, Straps, Spare fuses, Strong case

Web: http://www.radsys.lv
E-mail: radsys@radsys.lv

RADAR Systems, Inc. Ground Penetrating Radars

Zond-12e

150-75-38 Mhz Antenna System

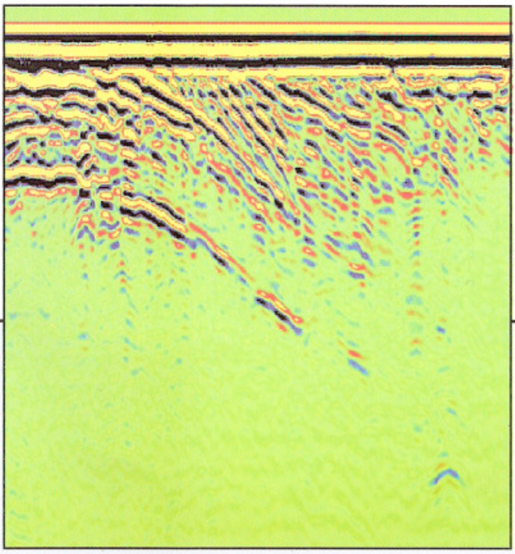
UNSHIELDED, AIR COUPLED

WEIGHT: 2 kg to 7 kg (depends on frequency)

POWER: 0.35 A @ 12 V DC by cable from control unit

TRANSMITTER OUTPUT: 200 V

RECEIVER SENSITIVITY: 50 μV



Sounding of sand hill

Web: http://www.radsys.lv
E-mail: radsys@radsys.lv

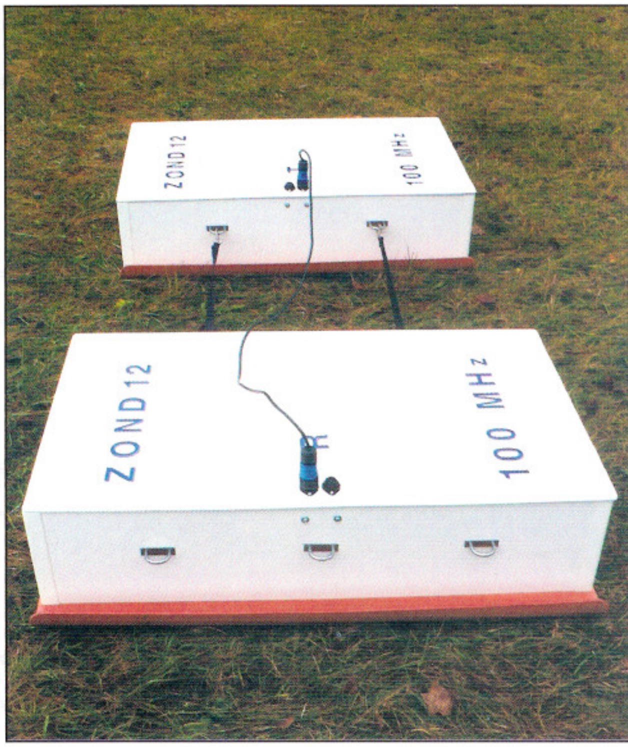
RADAR Systems, Inc.

Ground Penetrating Radars

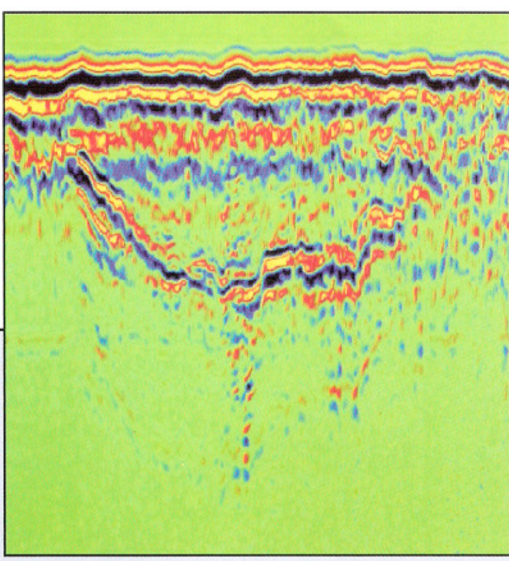
Zond-12e

100 Mhz Antenna System

SHIELDED, SURFACE COUPLED



PERFORMANCE: separated transmitting and receiving
DIMENSION: 93x65x21 cm each
WEIGHT: 13 kg each
POWER: 0.35 A @ 12 V DC by cable from control unit
TRANSMITTER OUTPUT: 400 V
RECEIVER SENSITIVITY: 50 μV



Sounding of sand hill

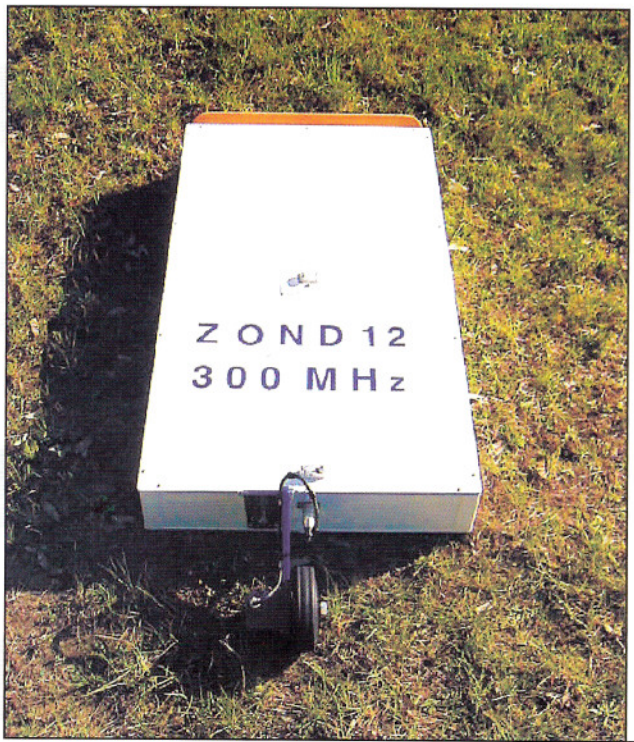
Web: http://www.radsys.lv
E-mail: radsys@radsys.lv

RADAR Systems, Inc. Ground Penetrating Radars

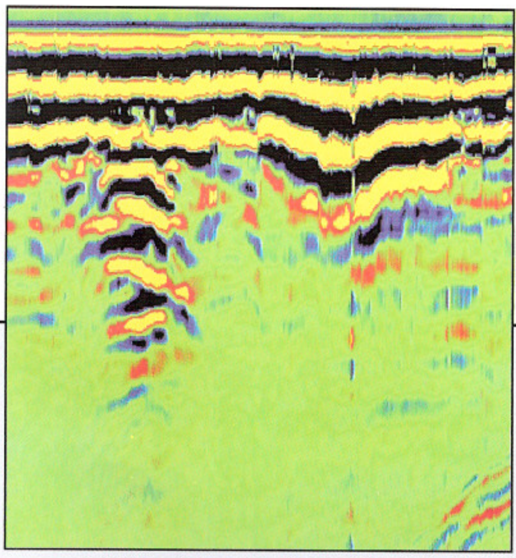
Zond-12e

300 Mhz Antenna Unit

SHIELDED, SURFACE COUPLED



DIMENSION: 102x53x12 cm
WEIGHT: 10 kg
POWER: 0.35 A @ 12 V DC by cable from control unit
TRANSMITTER OUTPUT: 400 V
RECEIVER SENSITIVITY: 50 μV



Karst cavity detection

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E-mail: radsys@radsys.lv

RADAR Systems, Inc.

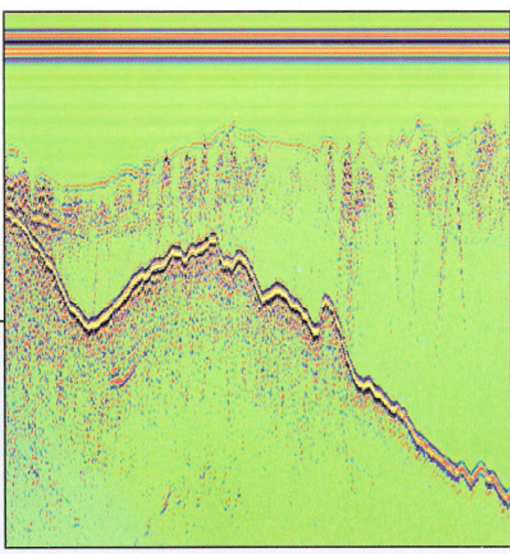
Ground Penetrating Radars

Zond-12e

500 Mhz Antenna Unit

SHIELDED, SURFACE COUPLED

DIMENSION: 72x33x12 cm
WEIGHT: 5.5 kg
POWER: 0.35 A @ 12 V DC by cable from control unit
TRANSMITTER OUTPUT: 400 V
RECEIVER SENSITIVITY: 50 μV



Lake profiling

Web: http://www.radsys.lv
E-mail: radsys@radsys.lv

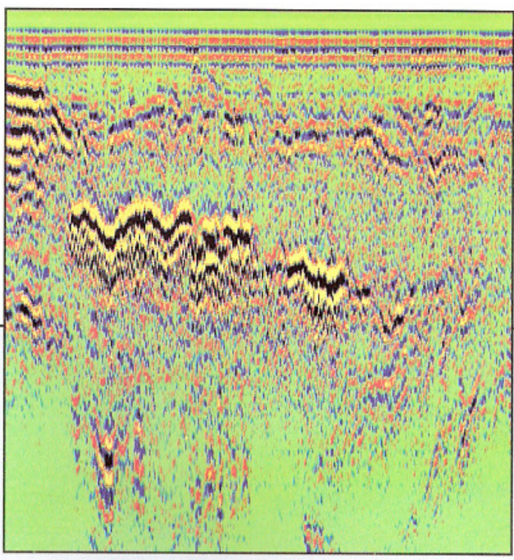
RADAR Systems, Inc.
Ground Penetrating Radars

Zond-12e

750 Mhz Antenna System

SHIELDED, AIR COUPLED

PERFORMANCE: separated transmitting and receiving.
DIMENSION: 35x20x15 cm each
WEIGHT: 2 kg each
POWER: 0.25 A @ 12 V DC by cable from control unit
TRANSMITTER OUTPUT: 200 V
RECEIVER SENSITIVITY: 50 μV



Railways embankment profiling

Web: http://www.radsys.lv
E-mail: radsys@radsys.lv

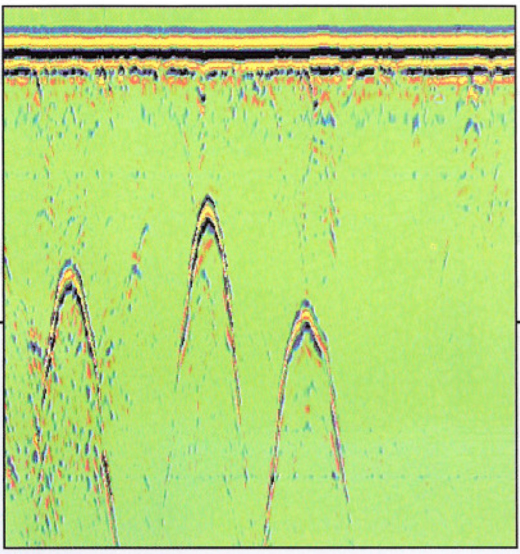
RADAR Systems, Inc. Ground Penetrating Radars

Zond-12e

900 Mhz Antenna Unit

SHIELDED, SURFACE COUPLED

DIMENSION: 52x23.5x12 cm
WEIGHT: 3 kg
POWER: 0.35 A @ 12 V DC by cable from control unit
TRANSMITTER OUTPUT: 400 V
RECEIVER SENSITIVITY: 50 μV



Detection of pipes

Web: http://www.radsys.lv
E-mail: radsys@radsys.lv

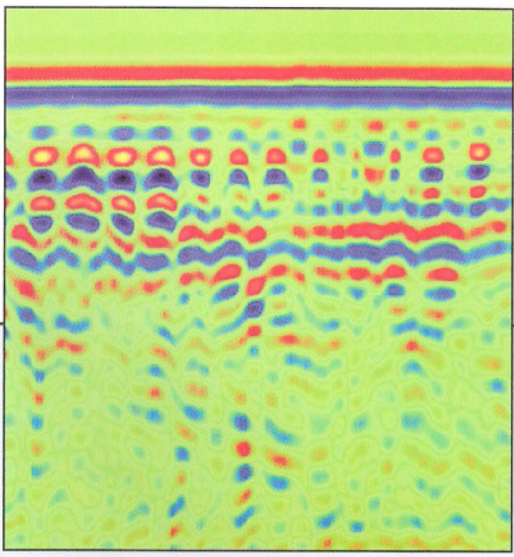
RADAR Systems, Inc.
Ground Penetrating Radars

Zond-12e

1.5 Ghz Antenna Unit

SHIELDED, SURFACE COUPLED

DIMENSION: 30x12x11 cm
WEIGHT: 1.5 kg
POWER: 0.25 A @ 12 V DC by cable from control unit
TRANSMITTER OUTPUT: 200 V
RECEIVER SENSITIVITY: 50 μV



Detection of rebars in concrete

Web: http://www.radsys.lv
E-mail: radsys@radsys.lv

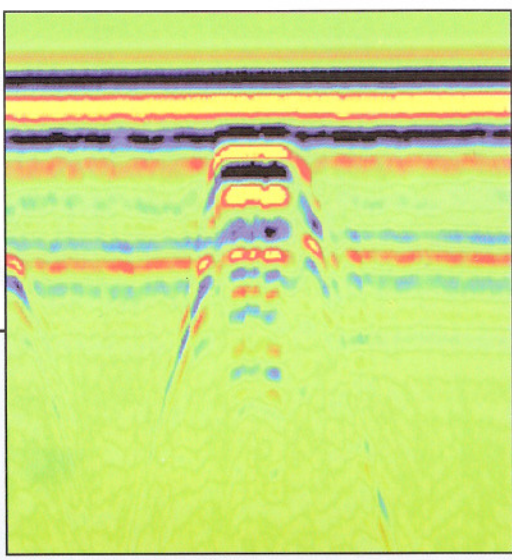
RADAR Systems, Inc. Ground Penetrating Radars

Zond-12e

2 Ghz Antenna Unit

UNSHIELDED, SURFACE COUPLED

DIMENSION: 27x13.5x13 cm
WEIGHT: 1.2 kg
POWER: 0.25 A @ 12 V DC by cable from control unit
TRANSMITTER OUTPUT: 200 V
RECEIVER SENSITIVITY: 50 μV



Detection of metallic safe in brick wall

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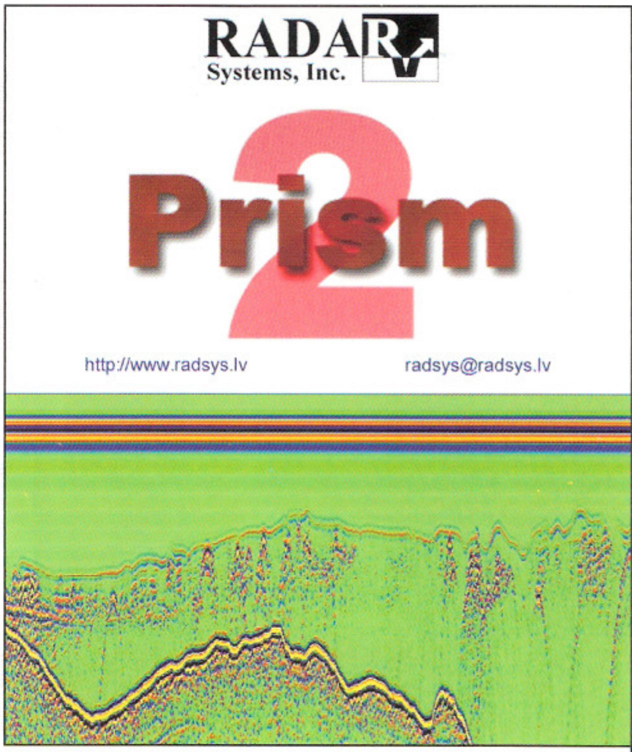
RADAR Systems, Inc.

Ground Penetrating Radars

Zond-12e

Prism2

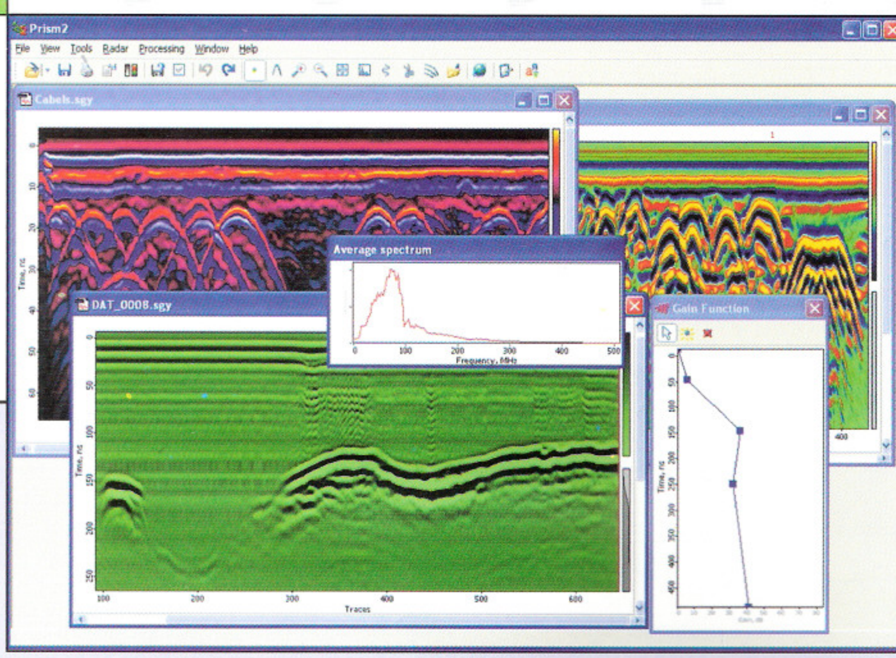
GPR SOFTWARE



DATA COLLECTION:
- Colored or grayscale acquisition mode
- Continuos profile or stepped mode
- Digital gain function applying
- Record of current coordinates from GPS receiver
- Distance measurement from wheel

DISPLAY MODE:
- user selected colour or grey scale line scan, wiggle plot
- integrated multi-windows environment
- user-friendly interface
- different data formats: SEG-Y, RadSys, GSSI
- spectra calculations
- output to printer supported by Windows
- velocities and depth evaluation via diffracting options
- 10 point digital gain function
- path finder tool for GPS coordinates
- stepped Zoom In & Zoom Out

PROCESSING:
- frequency bandpass filters
- efficient amplitude correction
- migration
- envelope
- topography
- x-interpolation

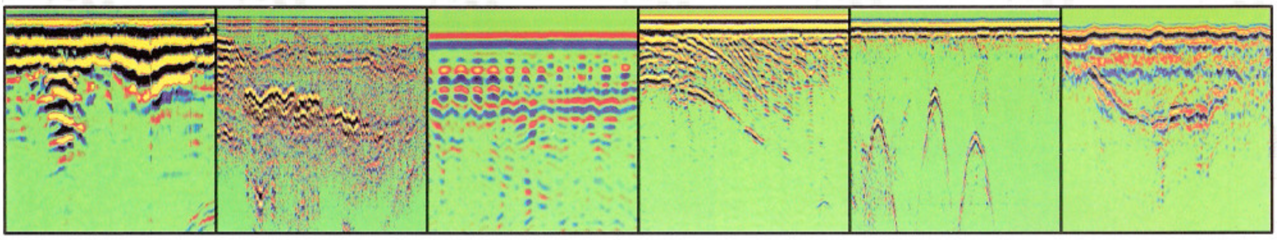


Web: http://www.radsys.lv
E-mail: radsys@radsys.lv

RADAR Systems, Inc.

Ground Penetrating Radars

Zond-12e



PM PRESTİJ

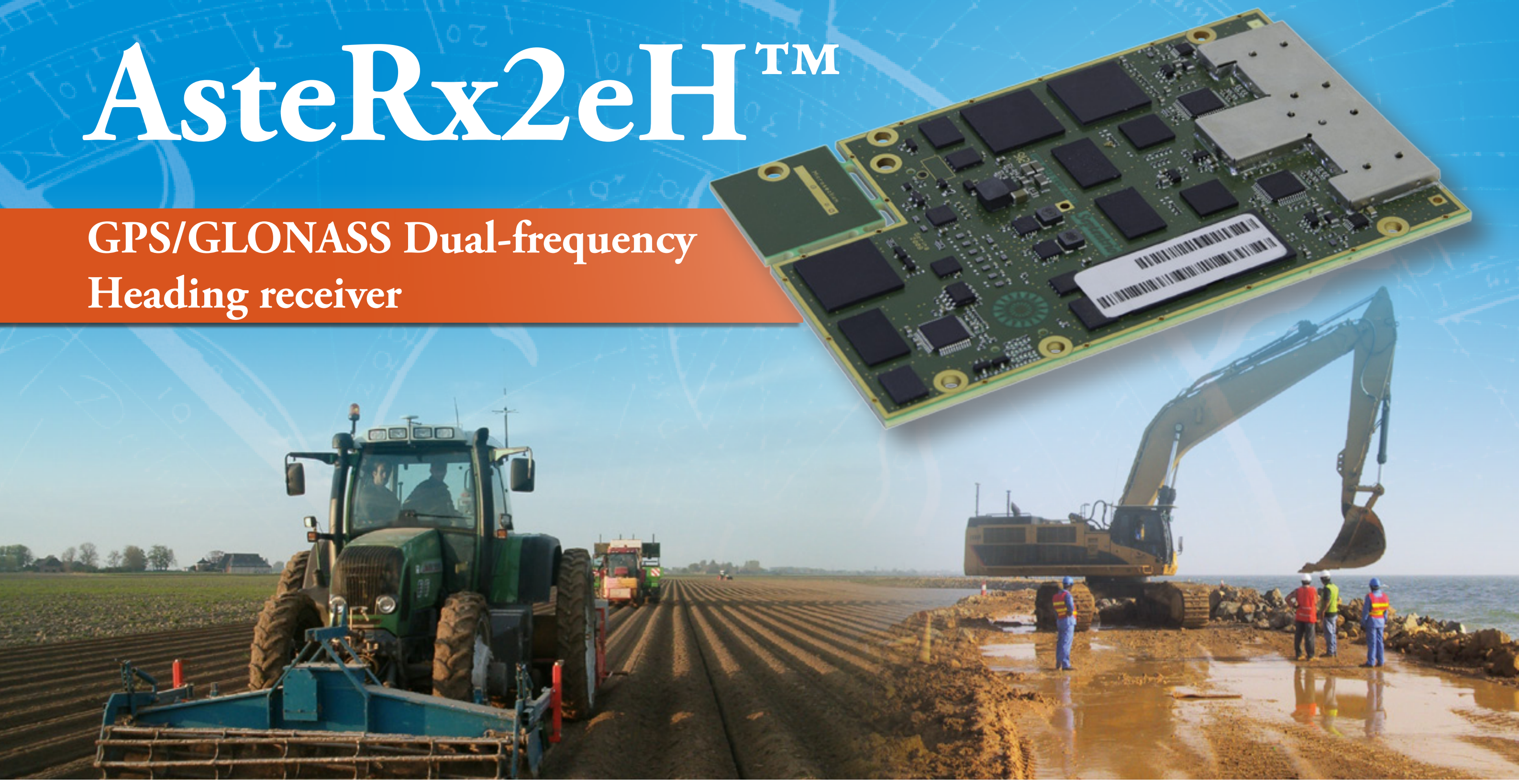
MÜHENDİSLİK MÜŞAVİRLİK
YERALTI ARAŞTIRMALARI

ISO 9001 : 2000 REGISTERED FIRM
QI3390/07 - 99020095

Mahmutbey Yolu. Sakarya Çıkmazı Yazıcıoğlu iş Merkezi No:3 Kat:5 Daire: 13 Şirinevler / İSTANBUL
Tel: 0 212 654 82 57 – 0212 639 43 11 Fax: 0 212 551 81 44
e-mail : info@pmprestij.com web: www.pmprestij.com

AsteRx2eH™

GPS/GLONASS Dual-frequency Heading receiver



Single-board dual-frequency dual-antenna GPS/GLONASS heading receiver, specially designed for demanding machine control, marine survey and other multi-antenna applications.

Single-board dual-antenna GPS/GLONASS heading receiver

With two antenna inputs feeding 272 multi-frequency tracking channels, AsteRx2eH provides a compact and low power solution for cm-level RTK positioning combined with accurate heading information, at up to 20 Hz. AsteRx2eH tracks both GLONASS and GPS satellites, improving the availability and accuracy in challenging environments where signal blocking by buildings, trees, mountains and other obstructions provide limitations to GPS only systems.

World-class performance with GNSS+

AsteRx2eH offers advanced signal processing for optimal performance under difficult conditions, including:

- Track+: for robust tracking of weak signals
- LOCK+™: provides stable tracking under high vibration and dynamic conditions
- APME+: Advanced code and phase multipath mitigation technology

Easy to integrate

The AsteRx2eH is available as an OEM board for integration, or in a tough compact waterproof aluminium housing (AsteRx2eH PRO) for use in any outdoor environment. The RF section of board is shielded to help avoid EMI issues. The AsteRx2eH interface is fully documented providing the integrator with full flexibility. The interface is compatible with other receivers of the AsteRx2e-family making it easy to build solutions for different accuracy and application requirements with no redesign.

A comprehensive GNSS SW-toolset

The RxTools package includes the intuitive RxControl GUI for receiver configuration and monitoring. Various tools for mission planning, data logging, replay and analysis, reporting, and more, are included.

Key Features

- Single board dual-Antenna GPS/GLONASS receiver
- Precise heading calculation
- cm-level positioning accuracy
- Septentrio GNSS+ algorithms for robust industrial performance
- Easy to integrate, fully documented interface language
- A comprehensive GNSS SW-toolset

Septentrio satellite navigation

Versatile OEM Receivers for Demanding Applications

www.septentrio.com • info@septentrio.com
Septentrio nv, Greenhill Campus, Interleuvenlaan 15G, 3001 Leuven, Belgium
Phone +32 (0)16 300 800 • Fax +32 (0)16 221 640

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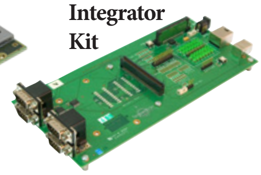
AsteRx2eH™

GPS/GLONASS Dual-frequency Heading receiver

AsteRx2eH PRO



Integrator Kit

AsteRx2eH OEM

FEATURES

- Dual-frequency L1/L2 code/carrier tracking of GPS and GLONASS signals on 2 antennas.
- 272 hardware channels for simultaneous tracking of all visible GPS and GLONASS satellite signals
- Simultaneous RTK and heading calculation
- Up to 20 Hz measurement, position and orientation update rate (user selectable)
- Lock+™ tracking technology
- Automatic or manual antenna calibration
- A Posteriori Multipath Estimator (APME)
- Innovative and flexible power management under user control.
- Includes up to 3 SBAS channels (EGNOS, WAAS, other)
- x PPS output (x = 1, 2, 5, 10)
- 2 Event markers
- RAIM
- Raw data output (code, carrier, navigation data)
- Four hi-speed serial ports
- 1 full speed USB port
- Ethernet
- Highly compact and fully documented Septentrio Binary Format (SBF) output
- NMEA v2.30 output format, (10 Hz max)
- RTCM v2.2, 2.3, 3.0 or 3.1
- CMR2.0 and CMR+
- Compact OEM board and housed solution
- Internal data logging in housed receiver (2GB)
- Includes intuitive GUI (RxControl) and detailed operating and installation manual

PHYSICAL AND ENVIRONMENTAL

OEM	
Size	77 x 120 mm
weight	90 g
Input voltage	+3.0 – 5.5 VDC
PRO	
size	245 x 140 x 37 mm
weight	980 g
Input voltage	9-30 VDC
Antenna LNA Power Output	
Output voltage	+ 5 VDC
Maximum current	200 mA
Power consumption	5 W typical
Operating temperature	-40 to +85 °C
Storage temperature	-40 to +85 °C
Humidity	5 % to 95 % (non condensing)

Connectors

Antenna	2 x TNC female
10 MHz in	BNC female
PPS out	BNC female
Power	ODU 3 pins female
COM/USB	ODU 7 pins female
IN	ODU 7 pins female
OUT	ODU 5 pins female
Ethernet	ODU 4 pins female

PERFORMANCE

Position accuracy[1,2,3,6]

	Horizontal	Vertical
Standalone	1.3 m	1.9 m
SBAS	0.6 m	0.8 m
DGPS	0.5 m	0.9 m
Veripos Ultra/APEX[18]	0.10 m	0.20 m
TERRASTAR D[19]	0.10 m	0.20 m

RTK performance[1,14]	
Horizontal accuracy[3]	0.6 cm + 0.5 ppm
Vertical accuracy[3]	1 cm + 1 ppm
Average time to fix[4]	7 sec

Velocity Accuracy[1,2,3]

Horizontal[3]	Vertical[3]
0.8 cm/sec	1.3 cm/sec

Heading Accuracy	
1m antenna separation	
Heading	0.3°
Pitch/Roll	0.6°
10m antenna separation	
Heading	0.03°
Pitch/Roll	0.06°

Maximum Update rate	20 Hz
Latency	< 20 msec

Time accuracy[3]	
1PPS	10 nsec
Event accuracy	< 10 nsec
Time to first fix	
Cold start[10]	< 45 sec
Warm start[11]	< 20 sec
Re-acquisition	avg 1.2 sec
Tracking performance (C/N0 threshold)[12,13,15]	
Tracking	26 dB-Hz
Acquisition	33 dB-Hz
Acceleration[16]	10 g
Jerk[17]	4 g/sec

1 1-20 Hz measurement rate
2 Performance depends on environmental conditions
3 1σ level
4 Baseline < 20 km
5 C/N0 = 45 dB-Hz
6 Smoothed
7 Non-smoothed
8 Multipath mitigation disabled
9 Multipath mitigation enabled
10 No information available (no almanacs, no approximate position)
11 Ephemeris and approximate position known
12 95%
13 Max speed 600 m/sec
14 Fixed ambiguities
15 Depends on user settings of tracking loop parameters
16 During acquisition
17 During tracking
18 Requires service activation from Veripos Ltd.
19 Requires service activation from TERRASTAR.

OTHER SEPTENTRIO PRODUCTS

AsteRx-m – Ultra low power, smaller than credit card GPS/GLONASS dual-frequency RTK receiver, for integration in hand-held devices, mobile computing platforms and other space-constrained applications requiring high accuracy and low-power consumption.

AsteRx2e/2eL – Compact dual-frequency GPS/GLONASS receiver platform, offering top-quality GPS code and carrier phase data and dual-frequency positioning (including DGPS, RTK and PPP (AsteRx2eL)) at up to 25 Hz.

AsteRx3 – A Multi-frequency GPS/GLONASS/GALILEO receiver for demanding industrial applications, featuring precise RTK with extended baselines, advanced multipath and interference mitigation and exceptional tracking stability under high vibration conditions.

AsteRxi – IMU assisted Compact Dual-frequency GNSS receiver platform, offering a 50Hz RTK position based on integrated IMU and GNSS measurements. In addition attitude information such as heading, pitch and roll are provided even in shadowed environments where conventional GNSS receivers fail.

PolaRx4 – fully featured high performance GNSS receiver providing network operators and scientific users with high-quality tracking and measurement of all available and upcoming GNSS signals (GPS/GALILEO/GLONASS/COMPASS/SBAS)

PolaRxS – a multi-frequency multi-constellation receiver dedicated to ionospheric monitoring and space weather applications

PolaNt* – A set of lightweight sturdy precise positioning and survey single, dual- or multi-frequency GPS, GPS/GLONASS and GPS/GLONASS Galileo/L-band antennas for use with the PolaRx and AsteRx receiver family.

Chokering MC – A multi-frequency GPS/GLONASS/Galileo L1/L2/E5abAltBOC chokering antenna for use with the PolaRx receiver family

RxTools – A suite of software applications for easy control of PolaRx and AsteRx receivers, and for easy manipulation, analysis and reporting of the data generated with these receivers

RxMobile – A unique intuitive, portable GUI field controller for the Septentrio receivers. RxMobile allows controlling the receiver, monitoring the navigation solution and accessing its functions in the field in the same intuitive way as with RxControl.

Versatile OEM Receivers for Demanding Applications

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SATELLINE-EASy

SATELLINE-EASy is a state-of-the-art transceiver radio modem providing a compact and flexible solution for many different long range applications. It can be equipped with an LCD and push buttons for facilitating the configuration of the radio modem.

Setting up a local data transfer network is quick and cost effective with SATEL radio modems. The wireless network is independent and free of operator services. The cost of operation is either free of charge or fixed, depending on the frequency used. SATEL radio modems are type-approved in over 50 countries.

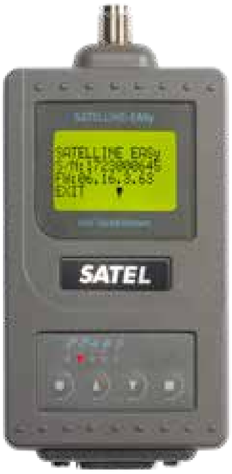
SATEL radio modems are always on line and provide reliable, real-time data communications over distances ranging from tens or hundreds of metres up to around 80 kilometres. Thanks to a store and forward function, any radio modem in a network can be used as a master station, substation and / or re-peater.

SATEL radio modem networks are flexible, easy to expand and can cover a wide variety of solutions from simple point-to-point connections to large net-works comprising hundreds of modems. Even for ex-panded networks, only one operating frequency is required.

SATEL, Meriniitynkatu 17 P.O.Box 142,
FI-24101 Salo, FINLAND
Tel. +358 2 777 7800
info@satel.com

SATEL

Mission-Critical Connectivity



SATELLINE-EASy

- SATELLINE-EASy has two operating voltage levels to choose and low power consumption.
- The channel spacings 12.5, 20 and 25 kHz are software-selectable and the output power of 1W enables long connection distances.
- It has a wide 90 MHz / 70 MHz tuning range and the operation frequency can be selected within the ranges 330...420 MHz and 403...473 MHz.
- SATELLINE-EASy complies with the EN 300 113, EN 301 489-1, -5, EN 60950-1 and FCC Part 90 specifications.
- SATELLINE-EASy is also available as an IP67 product with 35W output power. You can find more information about the product in the SATELLINE-EASy Pro.

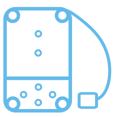
SATELLINE-EASy 869

- SATELLINE-EASy 869 is ready to use on the Pan-European licence free channels with default settings. It is allocated for narrowband telemetry, alarm and data transfer applications.
- SATELLINE-EASy 869 complies the EN 300 220-1, -2, EN 301 489-1, -3 and EN 60950-1.

	SATELLINE-EASy	SATELLINE-EASy 869
Frequency	330...420 MHz / 403 ... 473 MHz	869.400 ... 869.650 MHz
Channel Width	12.5 kHz / 20 kHz / 25 kHz (Software selectable)	25 kHz
Tuning Range	90 MHz / 70 MHz	0.25 MHz
Adjacent Channel Power	< -60 dBc	< -64 dBc
Sensitivity BER < 10E-3 (FEC ON)	-114 dBm @ 12.5 kHz -111 dBm @ 25 kHz	-111 dBm
Adjacent Channel Selectivity (FEC ON)	>47 dB @ 12.5 kHz >52 dB @ 25 kHz	>52 dB
Data Speed of Radio Interface	19200 bps (25 kHz channel) 9600 bps (12.5 / 20 kHz channel)	19200 bps (25 kHz channel)
Power Consumption Save Modes	<1.2 W (Receive) <7 W (Transmit 1 W) Sleep: 0.12 W / DTR: 10 mW	<1.2 W (Receive) <3.8 W (Transmit 0.5 W) Sleep: 0.12 W / DTR: 10 mW
Modulation	4FSK, GMSK	4FSK
Operating Voltage	2 options: +3 ... +9 Vdc or +6 ... +30 Vdc	+6 ... +30 Vdc
Carrier Power	100, 200, 500, 1000 mW	10, 20, 50,100, 200, 500 mW
Frequency Error Tolerance	< 1 kHz	< 2.5 kHz
Spurious Emission	< -100 dBm (RX), < -80 dBm on 3rd harmonics @ 1215 - 1240 MHz (TX)	< -57dBm (RX/TX)

GENERAL	
Blocking (FEC ON)	>86 dB
Selectivity at ±50 kHz	>67 dB
Type of Emission	F1D
Communication Mode	Half-Duplex
Carrier Power Stability	<± 1.5 dB
Spurious Radiation	< 2 nW
Intermodulation Attenuation	>60 dB
Electrical Interface	Port1 fixed: RS-232 Port2 options: LVTTL, TTL or RS-232 / 422 (Port2 RS-232 / 422 is programmable)
Interface Connector	D15, female
Data Speed of Serial Interface	300 – 38400 bps
Data format	Asynchronous data
Temperature range	-25 °C ... +55 °C (tests acc. to ETSI standards) -40 °C ... +75 °C (absolute minimum / maximum) -40 °C … +85 °C (storage)
Antenna Connector	TNC, 50 ohm, female
Construction	Aluminium housing
Size H x W x D / Weight	139 x 67 x 29 mm / 250 g

Values are subject to change without notice.



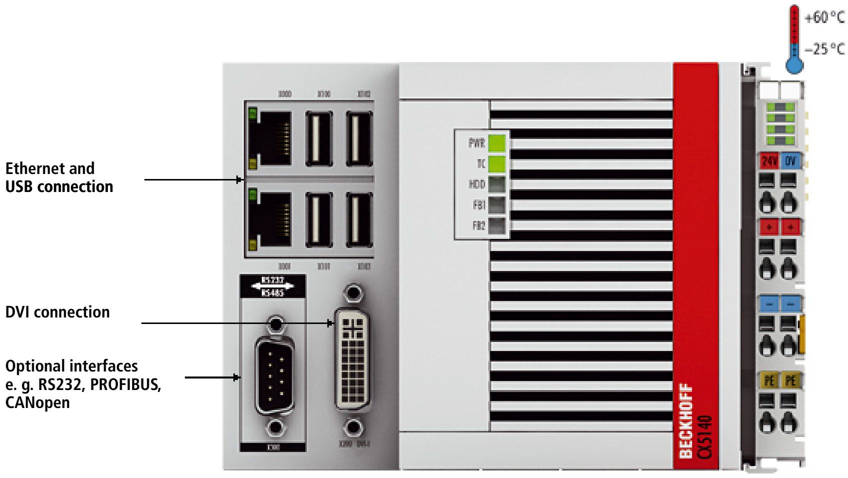
SATELLINE-EASy radio modems are also available as radio modules (Size: 88 x 49 x 9 mm / 50 g). You can find more information about SATELLINE-M3-TR1 and SATELLINE-M3-TR1 869 in the module brochure.

Distributor:

SATEL

Mission-Critical Connectivity

www.satel.com



CX5140 | Embedded PC with Intel® Atom™ processor

CX5120, CX5130 and CX5140 are Embedded PCs from the CX5100 series based on the Intel® Atom™ multi-core processors. They differ from one another in housing width and CPU type. What is new is that the available Atom™ CPUs now also introduce genuine multi-core technology, extending up to quad-core, into the compact Embedded PC segment. Since the new devices are an extension of the existing CX5000 series, they are equipped with identical hardware interfaces. Two independent Gigabit-capable Ethernet interfaces as well as four USB 2.0 and one DVI-I interface are available. A multitude of further connection options and gateway functions is created by the multi-option interface, which can be pre-equipped ex factory, as well as the I/O level, which can optionally consist of either E-Bus or K-Bus Terminals.

All devices in the series are characterised by low power consumption and fanless design.

Depending on the installed TwinCAT runtime environment, the CX5100 can be used for implementing PLC or PLC/Motion Control projects with or without visualisation. The execution of Motion Control applications with interpolating axis movements is also possible.

The extended operating temperature range from -25 to +60 °C enables the use of the CX5100 Embedded PCs in climatically demanding environments.

Like the CX5000, the CX5100 series has a compact design; a modular device with extension modules like in the CX2000 series is not available.

The order number of the basic CPU module can be derived as follows:

CX5140-01ST

- 0 = no TwinCAT
- 1 = with TwinCAT 2 PLC runtime
- 2 = with TwinCAT 2 NC PTP runtime
- 3 = with TwinCAT 2 NC I runtime
- 5 = TwinCAT 3 runtime (XAR)

- 0 = no operating system
- 1 = operating system Windows Embedded Compact 7
- 2 = operating system Windows Embedded Standard 7 P 32 bit
- 3 = operating system Windows Embedded Standard 7 P 64 bit
- 4 = Windows 10 IoT Enterprise LTSB 32 bit
- 5 = Windows 10 IoT Enterprise LTSB 64 bit

Since not all combinations make sense, the table "Ordering information" contains a breakdown of the permissible combinations.

Optional interfaces:

- CX5140-N020 = audio interface
- CX5140-N030 = RS232, D-sub plug
- CX5140-N031 = RS422/RS485, D-sub socket
- CX5140-M310 = PROFIBUS master, D-sub socket, 9-pin
- CX5140-B310 = PROFIBUS slave, D-sub socket, 9-pin
- CX5140-M510 = CANopen master, D-sub plug, 9-pin
- CX5140-B510 = CANopen slave, D-sub plug, 9-pin
- CX5140-M930 = PROFINET RT, controller
- CX5140-B930 = PROFINET RT, device, Ethernet (2 x RJ45 switch)
- CX5140-B931 = PROFINET IRT, device, Ethernet (2 x RJ45 switch)
- CX5140-B950 = EtherNet/IP slave, Ethernet (2 x RJ45 switch)
- CX5140-B110 = EtherCAT slave, EtherCAT IN and OUT (2 x RJ45)

Technical data	CX5140
Processor	Intel® Atom™ E3845, 1.91 GHz
Number of cores	4
Flash memory	slot for CFast card (card not included), slot for microSD card
Internal main memory	4 GB DDR3 RAM (not expandable)
Persistent memory	integrated 1-second UPS (1 MB on CFast card)
Interfaces	2 x RJ45, 10/100/1000 Mbit/s, DVI-I, 4 x USB 2.0, 1 x optional interface
Diagnostics LED	1 x power, 1 x TC status, 1 x flash access, 2 x bus status
Clock	internal battery-backed clock for time and date (battery exchangeable)
Operating system	Microsoft Windows Embedded Compact 7, Microsoft Windows Embedded Standard 7 P, Microsoft Windows 10 IoT Enterprise LTSB
Control software	TwinCAT 3 TwinCAT 2 PLC runtime, NC PTP runtime, NC I runtime
I/O connection	E-bus or K-bus, automatic recognition
Power supply	24 V DC (-15 %/+20 %)
Current supply E-bus/K-bus	2 A
Max. power loss	12 W (including the system interfaces)
Dimensions (W x H x D)	142 mm x 100 mm x 92 mm
Weight	approx. 960 g
Operating/storage temperature	-25…+60 °C/-40…+85 °C
Relative humidity	95 %, no condensation
Vibration/shock resistance	conforms to EN 60068-2-6/EN 60068-2-27
EMC immunity/emission	conforms to EN 61000-6-2/EN 61000-6-4
Protection class	IP 20
Approvals	CE, UL, Ex, IECEx
TC3 performance class	performance plus (50); please see here for an overview of all the TwinCAT 3 performance classes

Ordering information	no operating system	Windows Embedded Compact 7	Windows Embedded Standard 7 P 32 bit	Windows Embedded Standard 7 P 64 bit	Windows 10 IoT Enterprise LTSB 32 bit	Windows 10 IoT Enterprise LTSB 64 bit	no TwinCAT	TwinCAT 2 PLC runtime	TwinCAT 2 NC PTP runtime	TwinCAT 2 NC I runtime	Twi 3 run (XA
CX5140-0100	x	–	–	–	–	–	x	–	–	–	–
CX5140-0110	–	x	–	–	–	–	x	–	–	–	–
CX5140-0111	–	x	–	–	–	–	–	x	–	–	–
CX5140-0112	–	x	–	–	–	–	–	–	x	–	–
CX5140-0113	–	x	–	–	–	–	–	–	–	x	–
CX5140-0115	–	x	–	–	–	–	–	–	–	–	x
CX5140-0120	–	–	x	–	–	–	x	–	–	–	–
CX5140-0121	–	–	x	–	–	–	–	x	–	–	–
CX5140-0122	–	–	x	–	–	–	–	–	x	–	–
CX5140-0123	–	–	x	–	–	–	–	–	–	x	–
CX5140-0125	–	–	x	–	–	–	–	–	–	–	x
CX5140-0130	–	–	–	x	–	–	x	–	–	–	–
CX5140-0135	–	–	–	x	–	–	–	–	–	–	x
CX5140-0140	–	–	–	–	x	–	x	–	–	–	–
CX5140-0141	–	–	–	–	x	–	–	x	–	–	–
CX5140-0142	–	–	–	–	x	–	–	–	x	–	–
CX5140-0143	–	–	–	–	x	–	–	–	–	x	–
CX5140-0150	–	–	–	–	–	x	x	–	–	–	–
CX5140-0155	–	–	–	–	–	x	–	–	–	–	x

Accessories	
CX1900-0101	DVI-to-VGA passive adaptor for connecting a standard desktop VGA monitor to the CX system (singles out the VGA signals of the DVI-I interface).
CX2900-00xx	CFast cards: 2, 4, 8, 16, 32 GB CFast card
CX2900-0107	Device modification for fulfillment of ATEX Certification II 3 G Ex nA II T4 Gc and II 3 D Ex tc IIIC T135 °C Dc for CX5120, CX5130, CX5140 and CX9020: This option includes the modification and repositioning of the device label as well as a pre-mounted wire bow. The modification is a mandatory prerequisite for usage in hazardous areas as covered by the before mentioned certificate for ATEX Zone 2/22. Please also read the documentation for use in hazardous areas carefully.

Optional interfaces	
CX5140-N010	DVI-D interface, additional DVI-D port for clone or extended desktop operation
CX5140-N011	DisplayPort interface, additional DisplayPort for clone or extended desktop operation
CX5140-N020	audio interface, 3 x 3.5 mm jack sockets, Line In, Mic In, Line Out or 5.1 Surround
CX5140-N030	RS232 interface, D-sub plug, 9-pin
CX5140-N031	RS485 interface, D-sub socket, 9-pin, configuration as an end point, without echo, termination on
CX5140-N031-0001	RS485 interface, D-sub socket, 9-pin, configuration as an end point, with echo, termination on
CX5140-N031-0002	RS485 interface, D-sub socket, 9-pin, configuration as drop point, without echo, termination off
CX5140-N031-0003	RS485 interface, D-sub socket, 9-pin, configuration as drop point, with echo, termination off
CX5140-N031-0004	RS422 interface, D-sub socket, 9-pin, configuration as full duplex end point, termination on
CX5140-B110	EtherCAT slave interface, EtherCAT IN and OUT (2 x RJ45)
CX5140-M310	PROFIBUS master interface, D-sub socket, 9-pin
CX5140-B310	PROFIBUS slave interface, D-sub socket, 9-pin
CX5140-M510	CANopen master interface, D-sub plug, 9-pin
CX5140-B510	CANopen slave interface, D-sub plug, 9-pin
CX5140-M930	PROFINET RT, controller interface, Ethernet (2 x RJ45)
CX5140-B930	PROFINET RT, device interface, Ethernet (2 x RJ45 switched)
CX5140-B931	PROFINET IRT, device interface, Ethernet (2 x RJ45 switched), in combination with TwinCAT 3 only
CX5140-B950	EtherNet/IP slave interface, Ethernet (2 x RJ45 switched)

Product announcement	CX5140-B931, CX5140-B950: estimated market release on request

Search and locate

UPEX® 725 D

UXO Detector

- Simple one knob operation
- Large detection range
- Pinpointing by audio modulation
- Programmable delay steps
- Dynamic/static search mode
- Interference compensation
- Non-cooperative soil suppression

UPEX® 725 D — UXO Detektor

Application

UPEX® 725 D is the latest EBINGER design for UXO detection under difficult conditions such as ground mineralization and scrap. In addition to the simplicity in operation the UPEX® 725 D has the advantage that it can be programmed to fade out interfering signals from non-cooperative soil, magnetic rocks and small pieces of scrap metal. This improves productivity significantly.

To ease pinpointing the audio signal will be modulated upon target approach of the search head.

Constructional features

The UPEX® 725 D is a compact metal detector. It consists of a foldable oval search head which is flanged to a swivel joint, an extension rod, the electronic cylinder and the battery pack (respectively the battery container). On request UPEX® 725 D can be supplied with a telescopic extension rod with a flanged and (not exchangeable) 300 x 230 mm search head.

On the control section there is the rotary switch for the operation mode DYNAMIC/STATIC. The UPEX® 725 D comes with an internal stepping switch offering 6 settings to adapt the detector to the respective task. The flanged battery tube accommodates 6 c-cell batteries.

Delivery content

- Search head 300 x 230 mm
- Electronic cylinder
- Extension rod*
- Battery pack 11.1 V 4.4 Ah LION or customized power supply
- Charger
- Test plate

*Telescopic version only with flanged search head available.

Technical data

Power supply:	
Battery container 6 x 1,5 V (LR14)	operation time approx. 20 h (intermittent)
Rechargeable Ni MH batteries 9,6 V 2,1 Ah	operation time approx. 20 h (intermittent)
Li-ion battery pack 4,4 Ah	operation time approx. 35 to 40 h (intermittent)
Temperature range:	approx. - 10 to + 55 ° C
Dimensions:	
Short version with rech. battery	approx. 855 mm
Short version with dry battery	approx. 1105 mm
Long version with rech. battery	approx. 1.550 mm
Long version with dry battery	approx. 1800 mm
Length of extension rod	approx. 710 mm (customized variable)
Oval search head (exchangeable)	approx. 300 x 230 mm (standard size) 420 x 280 mm (large size)
Weight:	
Short version with rech. battery	approx. 1,75 kg
Long version with rech. battery	approx. 2,10 kg

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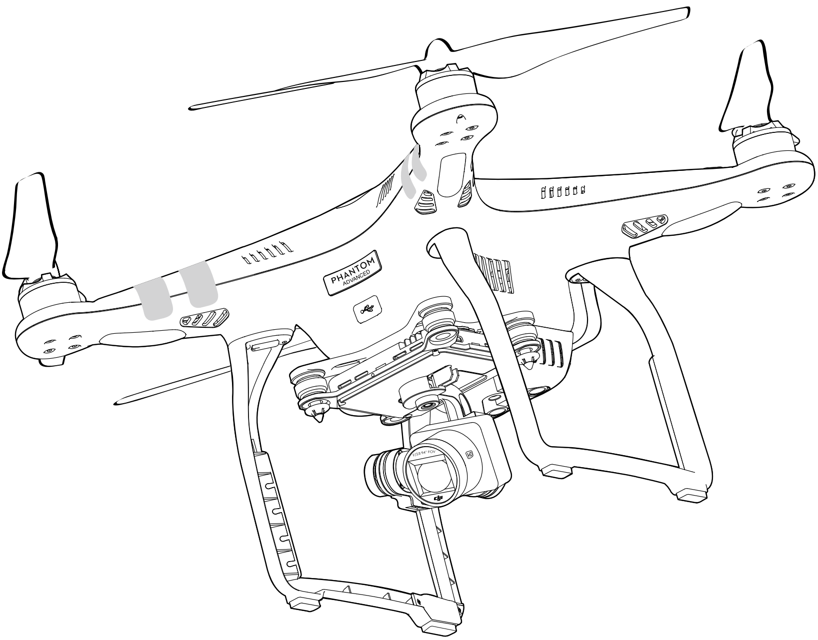
PHANTOM 3

ADVANCED

User Manual V1.0

2015.05



dji

Using this manual

Legends

Warning   Important   Hints and Tips   Reference

Read Before the First Flight

Read the following documents before using the Phantom 3 Advanced:

1. *In the Box*
2. *Phantom 3 Advanced User Manual*
3. *Phantom 3 Advanced Quick Start Guide*
4. *Phantom 3 Professional / Advanced Safety Guidelines and Disclaimer*
5. *Phantom 3 Professional / Advanced Intelligent Flight Battery Safety Guidelines*

We recommend that you watch all tutorial videos on the official DJI website and read the Disclaimer before you fly. Prepare for your first flight by reviewing the Phantom 3 Advanced Quick Start Guide and refer to the User Manual for more detailed information.

Video Tutorials

Please watch the tutorial videos at the link below, which demonstrates how to use Phantom 3 Professional safely:

http://www.dji.com/product/phantom-3/video

Download the DJI Pilot app

Download and install the DJI Pilot app before using the aircraft. Scan the QR code to the right to download the latest version.

The Android version of the DJI Pilot app is compatible with Android 4.1.2 or later.
The iOS version of the DJI Pilot app is compatible with iOS 8.0 or later.

Contents

Product Profile

This section introduces the Phantom 3 Advanced and lists the components of the aircraft and remote controller.

Product Profile

Introduction

The Phantom 3 Advanced represents the next generation of DJI quadcopters. It is capable of capturing 1080p video and transmitting an HD video signal out of the box. The built-in camera has an integrated gimbal to maximize stability while minimizing both weight and size. Even when no GPS signal is available, the Vision Positioning System allows the aircraft to hover accurately in place.

Feature Highlights

Camera and Gimbal: Phantom 3 Advanced has a fully integrated camera that shoots 1080p video at up to 60 frames per second and captures 12 megapixel photos. An enhanced sensor gives you greater clarity, lower noise, and better pictures than any previous flying camera.

HD Video Downlink: The low-latency HD downlink is powered by an enhanced version of DJI Lightbridge.

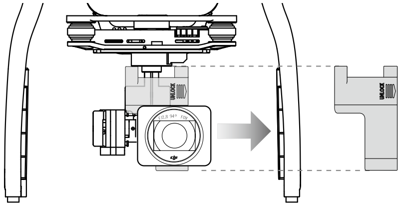
DJI Intelligent Flight Battery: The 4480 mAh DJI Intelligent Flight Battery features upgraded battery cells and an advanced power management system.

Flight Controller: The next-generation flight controller has been updated to provide a safer, more reliable flight experience. A newly implemented flight recorder stores critical data from each flight and the Vision Positioning System enhances hovering precision when flying indoors or in environments where GPS is unavailable.

Preparing the Aircraft

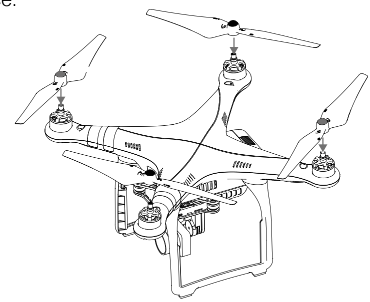
Removing Gimbal Clamp

Remove the gimbal clamp by sliding it to the right (when facing the nose of the aircraft), as shown below.



Attaching the Propellers:

Mount the propellers with black nuts on to motors with black axes and spin counter-clockwise to secure. Mount the propellers with grey nuts on to motors with gray axes and spin clockwise to secure. Be sure all propellers are securely in place.

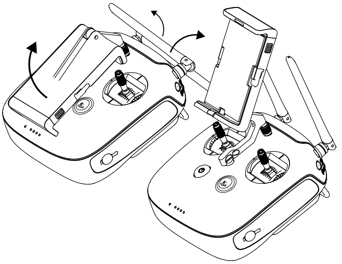


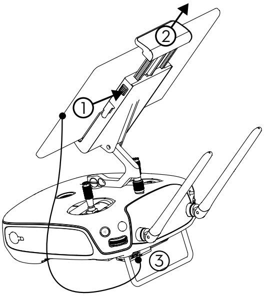
⚠ Place all propellers onto the correct motors and tighten by hand to lock them in position.

Preparing the Remote Controller:

Tilt the mobile device holder to the desired position, then adjust the antennas so they are facing outward.

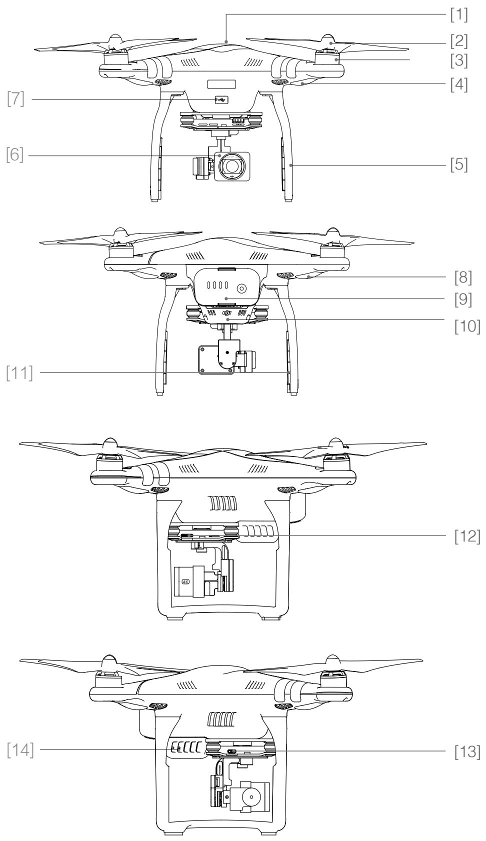
1. Press the button on the top right side of the mobile device holder to release the clamp, then adjust the clamp to fit the size of your mobile device.
2. Secure your mobile device in the clamp by pressing down, and connect your mobile device to the remote controller using a USB cable.
3. Plug one end of the cable into the mobile device, and the other end into the USB port on the back of the remote controller.





Product Profile

Aircraft Diagram



[1] GPS

[2] Propeller

[3] Motor

[4] Front LED Indicator

[5] Landing gear

[6] Gimbal and Camera

[7] Aircraft Micro-USB Port

[8] Aircraft Status Indicator

[9] Intelligent Flight Battery

[10] Vision Positioning Sensors

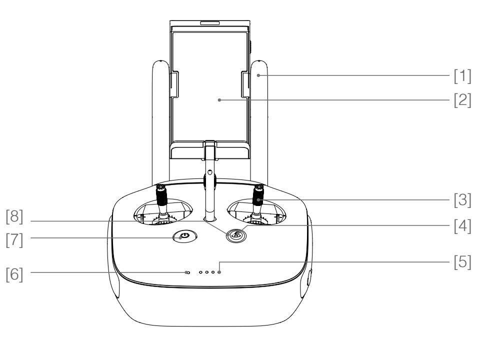
[11] Antennas

[12] Camera Micro-SD Card Slot

[13] Camera Micro-USB Port

[14] Link Button

Remote Controller Diagram



[1] Antennas

Relays aircraft control and video signal.

[2] Mobile Device Holder

Securely mounts your mobile device to the remote controller.

[3] Control Stick

Controls the orientation and movement of the aircraft.

[4] Return Home (RTH) Button

Press and hold the button to initiate Return to Home (RTH).

[5] Battery Level LEDs

Displays the battery level of the remote controller.

[6] Status LED

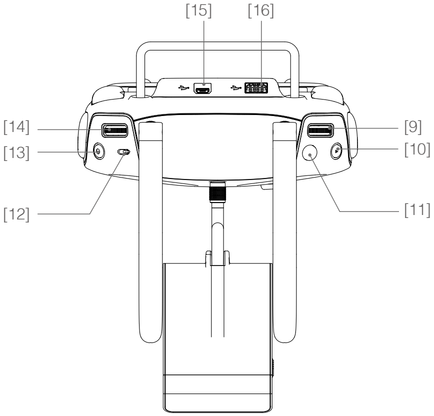
Displays the remote controller's system status.

[7] Power Button

Used to turn the remote controller on and off.

[8] RTH LED

Circular LED around the RTH button displays RTH status.



[9] Camera Settings Dial

Turn the dial to adjust camera settings. (Only functions when the remote controller is connected to a mobile device running the DJI Pilot app.)

[10] Playback Button

Playback the captured images or videos. (Only functions when the remote controller is connected to a mobile device running the DJI Pilot app.)

[11] Shutter Button

Press to take a photo. If burst mode is selected, the set number of photos will be taken with one press.

[12] Flight Mode Switch

Switch between P-mode, A-mode, and F-mode.

[13] Video Recording Button

Press to start recording video. Press again to stop recording.

[14] Gimbal Dial

Use this dial to control the tilt of the gimbal.

[15] Mircro-USB Port

Connect to a SD card reader to upgrade the firmware.

[16] USB Port

Connect to mobile device or to a USB port for firmware upgrade.

[17] C1 Button

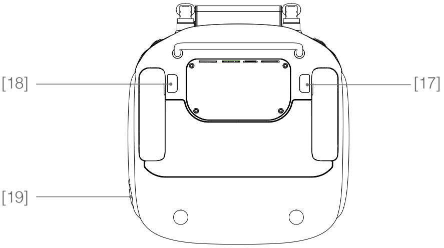
Customizable through the DJI Pilot app.

[18] C2 Button

Customizable through the DJI Pilot app.

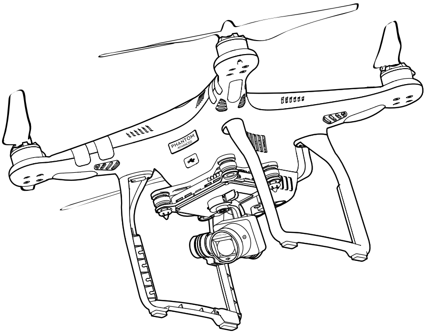
[19] Power Port

Connect to a power source to charge the battery of the remote controller.



Aircraft

This section introduces the features of the Flight Controller, Vision Positioning System, and the Intelligent Flight Battery



Aircraft

Flight Controller

The Phantom 3 Advanced's flight controller features several important upgrades, including a new flight mode. Safety modes include Failsafe and Return-to-Home. These features ensure the safe return of your aircraft if the control signal is lost. The flight controller can also save critical flight data from each flight to the on-board storage device.

Flight Mode

Three flight modes are available. The details of each flight mode are found below:

P-mode (Positioning) : P-mode works best when GPS signal is strong. There are three different states of P-mode, which will be automatically selected by the Phantom 3 Advanced depending on signal strength of GPS and Vision Positioning sensors :

- P-GPS: GPS and Vision Positioning both are available. The aircraft is using GPS for positioning.
- P-OPTI: Vision Positioning is available but the GPS signal strength is not sufficient. The aircraft is using only the Vision Positioning System for positioning.
- P-ATTI: Neither GPS nor Vision Positioning is available. The aircraft is using only its barometer for positioning, so only altitude can be stabilized.

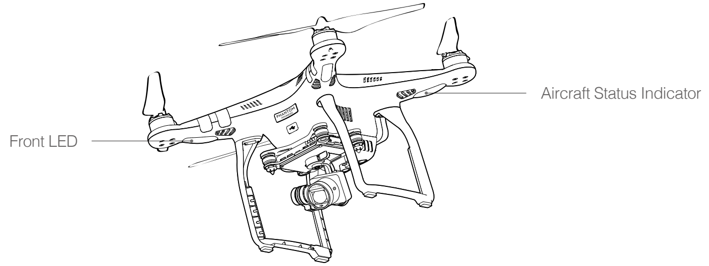
A-mode (Attitude): GPS and Vision Positioning System are not used for stabilization. The aircraft only uses its barometer. The aircraft can still automatically return to the home point if the control signal is lost and the Home Point was recorded successfully.

F-mode (Function): Intelligent Orientation Control (IOC) is activated in this mode. For more information about IOC, refer to the IOC section in the Appendix.

Use the Flight Controller mode switch to change the flight mode of the aircraft, refer to the "Flight Mode Switch" on P26 for more information.

Flight Status Indicator

The Phantom 3 Advanced has Front LEDs and Aircraft Status Indicators. The positions of these LEDs are shown in the figure below:



The Front LEDs show the orientation of the aircraft. The Front LEDs glow solid red when the aircraft is turned on to indicate the front (or nose) of the aircraft. The Aircraft Status Indicators communicate the system status of the flight controller. Refer to the table below for more information about the Aircraft Status Indicators:

Aircraft Status Indicator Description

Normal	
R G Y ...... Red, Green and Yellow Flash Alternatively	Turning On and Self-Checking
G Y ...... Green and Yellow Flash Alternatively	Aircraft Warming Up
G ...... Green Flashes Slowly	Safe to Fly (P-mode with GPS and Vision Positioning)
G X2 ...... Green Flashes Twice	Safe to Fly (P-mode with Vision Positioning but without GPS)
Y ...... Yellow Flashes Slowly	Safe to Fly (A-mode but No GPS and Vision Positioning)
Warning	
Y ...... Fast Yellow Flashing	Remote Controller Signal Lost
R ...... Slow Red Flashing	Low Battery Warning
R ...... Fast Red Flashing	Critical Battery Warning
R ...... Red Flashing Alternatively	IMU Error
R —— Solid Red	Critical Error
R Y ...... Red and Yellow Flash Alternatively	Compass Calibration Required

Return-to-Home (RTH)

The Return-to-Home (RTH) function brings the aircraft back to the last recorded Home Point. There are three types of RTH procedure: Smart RTH, Low Battery RTH, and Failsafe RTH. This section describes these three scenarios in detail.

	GPS	Description
Home Point		If a strong GPS signal was acquired before takeoff, the Home Point is the location from which the aircraft was launched. The GPS signal strength is indicated by the GPS icon ( ). The aircraft status indicator will blink rapidly when the home point is recorded.

Smart RTH

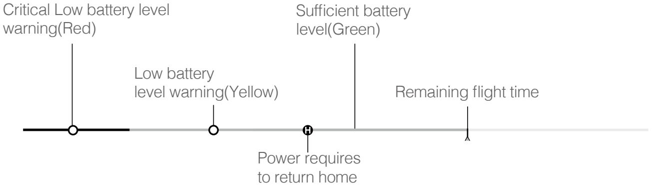
Use the RTH button on the remote controller (refer to "RTH button" on page 26 for more information) or tap the RTH button in the DJI Pilot app when GPS is available to initiate Smart RTH. The aircraft will then automatically return to the last recorded Home Point. You may use the remote controller's control sticks to control the aircraft's position to avoid a collision during the Smart RTH process. Press and hold the Smart RTH button once to start the process, and press the Smart RTH button again to terminate the procedure and regain full control of the aircraft.

Low Battery RTH

The low battery level failsafe is triggered when the DJI Intelligent Flight Battery is depleted to a point that may affect the safe return of the aircraft. Users are advised to return home or land the aircraft immediately when prompted. The DJI Pilot app will display a notice when a low battery warning is triggered. The aircraft will automatically return to the Home Point if no action is taken after a ten-second countdown. The user can cancel the RTH procedure by pressing the RTH button on the remote controller. The thresholds for these warnings are automatically determined based on the aircraft's current altitude and distance from the Home Point.

The aircraft will land automatically if the current battery level can only support the aircraft long enough to descend from its current altitude. The user can still use the remote controller to alter the aircraft's orientation during the landing process.

The Battery Level Indicator is displayed in the DJI Pilot app, and is described below:



Battery level Indicator

Battery Level Warning	Remark	Aircraft Status Indicator	DJI Pilot app	Flight Instructions
Low battery level warning	The battery power is low. Please land the aircraft.	Aircraft status indicator blinks RED slowly.	Tap "Go-home" to have the aircraft return to the Home point and land automatically, or "Cancel" to resume normal flight. If no action is taken, the aircraft will automatically go home and land after 10 seconds. Remote controller will sound an alarm.	Fly the aircraft back and land it as soon as possible, then stop the motors and replace the battery.
Critical Low battery level warning	The aircraft must land immediately.	Aircraft status indicator blinks RED quickly.	The DJI Pilot app display will flash red and the aircraft will start to descend. The remote controller will sound an alarm.	Allow the aircraft to descend and land automatically.
Estimated remaining flight time	Estimated remaining flight based on current battery level.	N/A	N/A	N/A

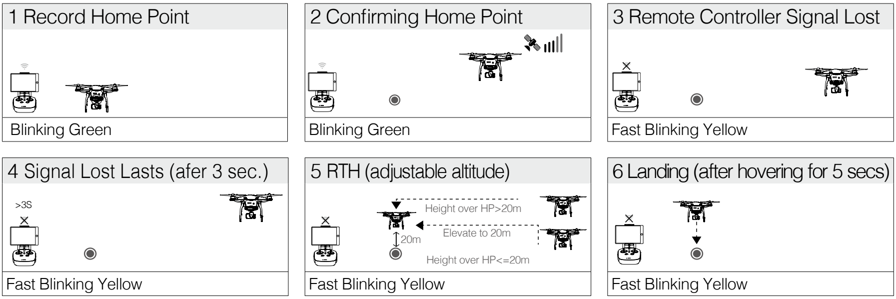
Aircraft

- When the Critical battery level warning is triggered and the aircraft begins to land automatically, you may push the throttle upward to make the aircraft hover at its current altitude, giving you an opportunity to navigate to a more appropriate landing location.
- The colored zones and markers on the battery level indicator bar reflect the estimated remaining flight time. They are automatically adjusted according to the aircraft's current location and status.

Failsafe RTH

If the Home Point was successfully recorded and the compass is functioning normally, Failsafe RTH will be automatically activated if the remote controller signal is lost for more than three seconds. The Return-to-Home process may be interrupted and the operator may regain control of the aircraft if the remote controller signal connection is re-established.

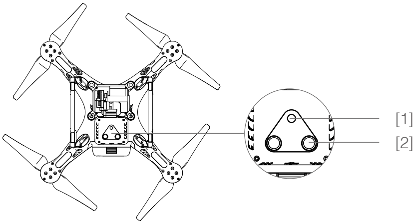
Failsafe Illustration



- The aircraft cannot avoid obstruction during the Failsafe RTH, therefore, it is important to set an suitable Failsafe altitude before each flight. Launch the DJI Pilot app and enter "Camera" and select "MODE" to set the Failsafe altitude.
- The aircraft will stop its ascent and return to the Home Point immediately if the throttle stick is moved during the Failsafe RTH procedure.

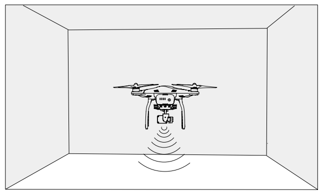
Vision Positioning System

The DJI Vision Positioning System uses ultrasound and image data to help the aircraft maintain its current position. With the help of Vision Positioning, your Phantom 3 Advanced can hover in place more precisely and fly indoors or in other environments where a GPS signal is not available. The main components of the Vision Positioning System are located on the bottom of your Phantom 3 Advanced; they include two ultrasonic sensors and one monocular camera.

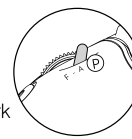


Using Vision Positioning

Vision Positioning is activated automatically when the Phantom 3 Advanced is turned on. No further action is required. Vision Positioning is typically used in indoor environments, where GPS is unavailable. Using the sensors that are built into the Vision Positioning system, the Phantom 3 Professional can hover precisely even without GPS.



Follow the steps below to use Vision Positioning:



1. Toggle the flight mode switch to P-mode.
2. Place the aircraft on a flat surface. Note that the Vision Positioning system cannot work properly on surfaces without clear pattern variations.
3. Turn on the aircraft. The aircraft status indicator will flash green two times, which indicates the Vision Positioning system is ready. Gently push the throttle up to lift off and the aircraft will hover in place.

⚠ The performance of your Vision Positioning System is affected by the surface over which it is flying. The ultrasonic sensors may not be able to accurately measure distances when operating above sound-absorbing materials. In addition, the camera may not function correctly in suboptimal environments. The aircraft will switch from P-mode to A-mode automatically if neither GPS nor Vision Positioning System are available. Operate the aircraft with great caution in the following situations:

- Flying over monochrome surfaces (e.g. pure black, pure white, pure red, pure green).
- Flying over a highly reflective surfaces.
- Flying at high speeds(over 8 m/s at 2 meters or over 4 m/s at 1 meter).
- Flying over water or transparent surfaces.
- Flying over moving surfaces or objects.
- Flying in an area where the lighting changes frequently or drastically.
- Flying over extremely dark (lux < 10) or bright (lux > 100,000) surfaces.
- Flying over surfaces that can absorb sound waves (e.g. thick carpet).
- Flying over surfaces without clear patterns or texture.
- Flying over surfaces with identical repeating patterns or textures (e.g. tiles with same design).
- Flying over inclined surfaces that will deflect sound waves away from the aircraft.

- Keep the sensors clean at all times. Dirt or other debris may adversely affect the effectiveness of the sensors.
- Vision Positioning is only effective when the aircraft is at altitudes of 0 to 3 meters.
- The Vision Positioning System may not function properly when the aircraft is flying over water.
- The Vision Positioning System may not be able to recognize pattern on the ground in low light conditions (less than 100 lux).
- Do not use other ultrasonic devices with frequency of 40 KHz when Vision Positioning system is in operation.
- Vision Positioning System may not be able to stabilize the aircraft when flying close to the ground (below 0.5 meters) in fast speed.

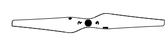
Keep the animals away from the aircraft when Vision Positioning system is activated. The sonar sensor emits high frequency sound that is only audible to some animals.

Flight Recorder

Flight data is automatically recorded to the internal storage of the aircraft. This includes flight telemetry, aircraft status information, and other parameters. Access these data from the DJI Pilot app through the Micro-USB Port on the aircraft.

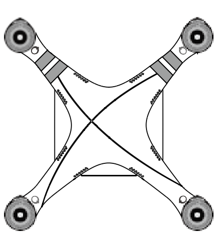
Attaching and Detaching the Propellers

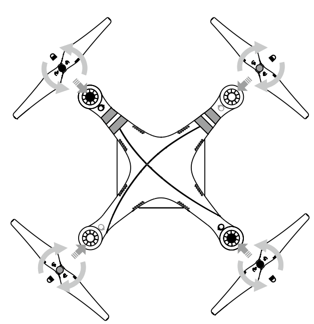
Use only DJI approved propellers with your Phantom 3 Advanced. The grey and black nuts on the propeller indicate where they should be attached and in which direction whey should spin. To attach the propellers properly, match the nut color with the motor axis color.

Propellers	Grey Nut	Black Nut
Figure		
Attach On	Motors with a grey axes	Motors with a black axes
Legends	Lock : Turn the propellers in the indicated direction to mount and tighten. Unlock : Turn the propellers in the indicated direction to loosen and remove.	

Attaching the Propellers

1. Attach the propellers with grey nuts onto the motors with grey axes and spin the propellers clockwise to secure them in place. Attach the propellers with black nuts onto the motors with black axes and spin the propellers counter-clockwise to secure them in place. Be sure to tighten each propeller by hand before flight.





- Ensure propellers are attached to its corresponding motors, otherwise the aircraft cannot take off.
- Wear gloves when handling propellers.
- Hand tighten each of the propellers on the corresponding motors to ensure it is attached firmly.

Detaching the Propellers

Hold the motor in place with one hand, then spin the propeller in the indicated unlock direction.

- Check that the propellers and motors are installed correctly and firmly before every flight.
- Ensure that all propellers are in good condition before each flight. DO NOT use aged, chipped, or broken propellers.
- To avoid injury, STAND CLEAR of and DO NOT touch propellers or motors when they are spinning.
- ONLY use original DJI propellers for a better and safer flight experience.

DJI Intelligent Flight Battery

The DJI Intelligent Flight Battery has a capacity of 4480 mAh, a voltage of 15.2 V, and a smart charge/discharge functionality. It should only be charged using an appropriate charger that has been approved by DJI.

The Intelligent Flight Battery must be fully charged before using it for the first time. Refer to "Charging the Intelligent Flight Battery" for more information.

Be aware that the output power of the supplied Phantom 3 Advanced charger is 57 W.

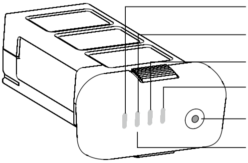
DJI Intelligent Flight Battery Functions

1. Battery Level Display: the LED indicators display the current battery level.
2. Battery Life Display: the LEDs display the current battery power cycle.
3. Auto-Discharging Function: To prevent swelling, the battery automatically discharges to below 65% of total power when it is idle for more than ten days. It takes around two days to discharge the battery to 65%. It is normal to feel moderate heat being emitted from the battery during the discharge process. Discharge thresholds can be set in the DJI Pilot app.
4. Balanced Charging: Automatically balances the voltage of each battery cell when charging.
5. Overcharge Protection: Charging automatically stops when the battery is fully charged.
6. Temperature Detection: The battery will only charge when the temperature is between 0°C (32°F) and 40°C (104°F).
7. Over Current Protection: The battery stops charging when high amperage (more than 8 A) is detected.
8. Over Discharge Protection: To prevent over-discharge damage, discharging automatically stops when the battery voltage reaches 12 V.
9. Short Circuit Protection: Automatically cuts the power supply when a short circuit is detected.

10. Battery Cell Damage Protection: DJI Pilot app displays a warning message when a damaged battery cell is detected.
11. Battery Error History: Browse the battery error history in the DJI Pilot app.
12. Sleep mode: To save power, the battery enters sleep mode after 20 minutes of inactivity.
13. Communication: Information pertaining to the battery's voltage, capacity, current, etc. is transmitted to the aircraft's main controller.

⚠ Refer to *Phantom 3 Professional / Advanced Intelligent Flight Battery Safety Guidelines* before use. Users take full responsibility for all operations and usage.

Using the Battery



Turning ON/OFF

Turning On: Press the Power Button once, then press again and hold for 2 seconds to turn on. The Power LED will turn red and the Battery Level Indicators will display the current battery level.

Turning Off: Press the Power Button once, then press again and hold for 2 seconds to turn off.

Low Temperature Notice:

1. Battery capacity is significantly reduced when flying in low temperature (< 0°C) environments.
2. It is not recommended that the battery be used in extremely low temperature (< -10°C) environments. Battery voltage should reach the appropriate level when operating environment with temperatures between -10°C and 5°C.
3. End the flight as soon as the DJI Pilot app displays the "Low Battery Level Warning" in low temperature environments.
4. Keep the battery indoors to warm it before flying in low temperature environments.
5. To ensure optimal performance of the battery, keep the battery temperature above 20°C.
6. The charger will stop charging the battery if the battery cell's temperature is not within the operating range (0°C ~ 40°C).

⚠ In cold environments, insert the battery into the battery compartment and allow the aircraft for approximately 1-2 minutes to warm up before taking off.

Checking the Battery Level

The Battery Level Indicators display how much power remains. When the battery is turned off, press the Power Button once. The Battery Level Indicators will light up to display the current battery level. See below for details.

The Battery Level Indicators will also show the current battery level during charging and discharging. The indicators are defined below.

▮ : LED is on. ✳ : LED is flashing.

▯ : LED is off.

Battery Level				
LED1	LED2	LED3	LED4	Battery Level
▮	▮	▮	▮	87.5%~100%
▮	▮	▮	✳	75%~87.5%
▮	▮	▮	▯	62.5%~75%
▮	▮	✳	▯	50%~62.5%
▮	▮	▯	▯	37.5%~50%
▮	✳	▯	▯	25%~37.5%
▮	▯	▯	▯	12.5%~25%
✳	▯	▯	▯	0%~12.5%
▯	▯	▯	▯	=0%

Battery life

Battery life refers to how many more times the battery can be discharged and recharged before it must be replaced. When the battery is turned off, press and hold the Power Button for 5 seconds to check the battery life. The Battery Level Indicators will light up and/or blink for two seconds, as shown below:

Battery Life				
LED1	LED2	LED3	LED4	Battery Life
▮	▮	▮	▮	90%~100%
▮	▮	▮	✳	80%~90%
▮	▮	▮	▯	70%~80%
▮	▮	✳	▯	60%~70%
▮	▮	▯	▯	50%~60%
▮	✳	▯	▯	40%~50%
▮	▯	▯	▯	30%~40%
✳	▯	▯	▯	20%~30%
▯	▯	▯	▯	below 20%

⚠ When battery life reaches 0%, it can no longer be used.

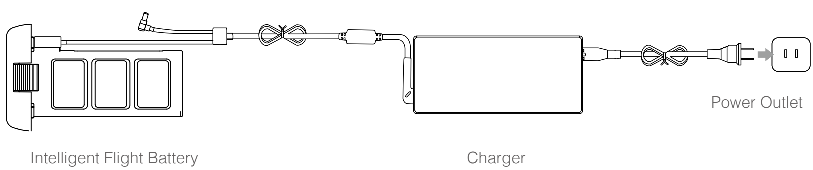
For more information about the battery, launch the DJI Pilot app and check the information that is listed under the battery tab.

Aircraft

Charging the Intelligent Flight Battery

1. Connect the Battery Charger to a power source (100-240 V 50/60 Hz).
2. Open the Protection Cap and connect the Intelligent Flight Battery to the Battery Charger. If the battery level is above 95%, turn on the battery before charging.
3. The Battery Level Indicator will display the current battery level as it is charging.
4. The Intelligent Flight Battery is fully charged when the Battery Level Indicators are all off.
5. Air-cool the Intelligent Flight Battery after each flight. Allow its temperature to drop to room temperature before storing it for an extended period.

⚠
- Do not charge the Intelligent Flight Battery and remote controller with standard charger at the same time, otherwise the charger may overheat.
- Always turn off the battery before inserting it or removing it from the Phantom 3 Advanced. Never insert or remove a battery when it is turned on.



Battery Level Indicators While Charging				
LED1	LED2	LED3	LED4	Battery Level
✳	□	□	□	0%~25%
✳	✳	□	□	25%~50%
✳	✳	✳	□	50%~75%
✳	✳	✳	✳	75%~100%
□	□	□	□	Fully Charged

Battery Protection LED Display

The table below shows battery protection mechanisms and corresponding LED patterns.

Battery Level Indicators while Charging					
LED1	LED2	LED3	LED4	Blinking Pattern	Battery Protection Item
□	✳	□	□	LED2 blinks twice per second	Over current detected
□	✳	□	□	LED2 blinks three times per second	Short circuit detected
□	□	✳	□	LED3 blinks twice per second	Over charge detected
□	□	✳	□	LED3 blinks three times per second	Over-voltage charger detected
□	□	□	✳	LED4 blinks twice per second	Charging temperature is too low
□	□	□	✳	LED4 blinks three times per second	Charging temperature is too high

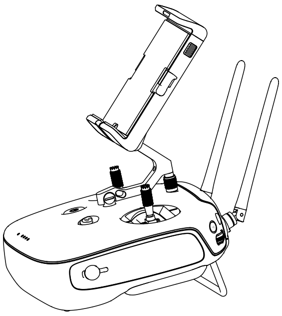
After these issues are resolved, press the Power Button to turn off the Battery Level Indicator. Unplug the Intelligent Flight Battery from the charger and plug it back in to resume charging. Note that you do not need to unplug and plug in the charger in the event of a room temperature error; the charger will resume charging when the temperature is within the allowable range.

⚠ DJI does not take any responsibility for damage caused by third-party chargers.

How to discharge your Intelligent Flight Battery:
Slow : Place the Intelligent Flight Battery into the Phantom 3 Advanced's Battery Compartment and turn it on. Leave it on until there is less than 8% of power left, or until the battery can no longer be turned on. Launch the DJI Pilot app to check battery levels.
Rapid : Fly the Phantom 3 Advanced outdoors until there is less than 8% of power left, or until the battery can no longer be turned on.

Remote Controller

This section describes the features of the remote controller and includes instructions for controlling the aircraft and the camera.



Remote Controller

Remote Controller Profile

The Phantom 3 Advanced remote controller is a multi-function wireless communication device that integrates the video downlink system and aircraft remote control system. The video downlink and aircraft remote control system operate at 2.4 GHz. The remote controller features a number of camera control functions, such as taking and previewing photos and videos, as well as controlling gimbal motion. The remote controller is powered by a 2S rechargeable battery. The battery level is displayed via LED indicators on the front panel of the remote controller.

- Compliance Version: The remote controller is compliant with both CE and FCC regulations.
- Operating Mode: Control can be set to Mode 1 or Mode 2, or to a custom mode.
- Mode 1: The right stick serves as the throttle.
- Mode 2: The left stick serves as the throttle.

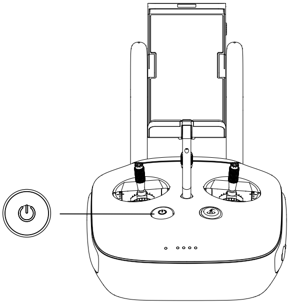
⚠ To prevent transmission interference, do not operate more than three aircrafts in the same area.

Using the Remote Controller

Turning the Remote Controller On and Off

The Phantom 3 Advanced remote controller is powered by a 2S rechargeable battery that has a capacity of 6000 mAh. The battery level is indicated via the Battery Level LEDs on the front panel. Follow the steps below to turn on your remote controller:

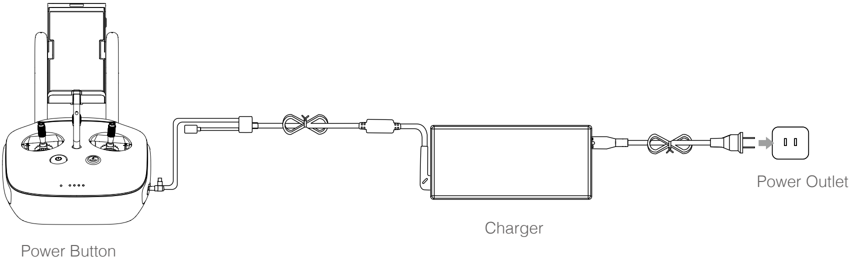
1. When the remote controller is turned off, press the Power Button once. The Battery Level LEDs will display the current battery level.
2. Press and hold the Power Button to turn on the remote controller.
3. The remote controller will beep when it is turned on. The Status LED will rapidly blink green, indicating that the remote controller is linking to the aircraft. The Status LEDs will glow solid green when linking is complete.
4. Repeat Step 2 to turn off the remote controller.



Charging the Remote Controller

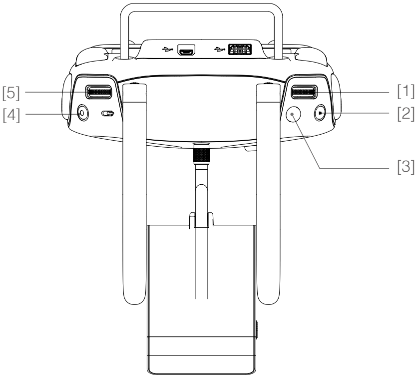
Charge the remote controller using the included charger. Refer to the figure below for more details.

Remote Controller



Controlling the Camera

Shoot videos/pictures, view recorded images, and adjust camera settings via the Shutter Button, Camera Settings Dial, Playback Button, and Video Recording Button on the remote controller.



[1] Camera Settings Dial

Turn the dial to adjust camera settings such as ISO, shutter speed, and aperture without letting go of the remote controller. Move the dial to left or right to scroll through pictures and videos in playback mode.

[2] Playback Button

Press to view images and videos that have already been captured.

[3] Shutter Button

Press to take a photo. If burst mode is activated, multiple photos will be taken with a single press.

[4] Video Recoding Button

Press once to start recording video, then press again to stop recording.

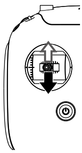
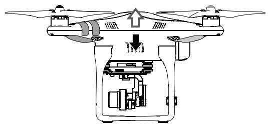
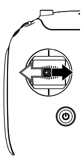
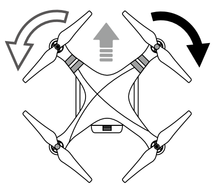
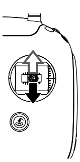
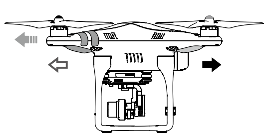
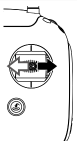
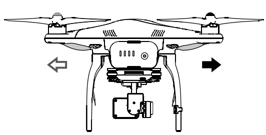
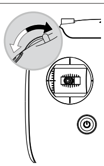
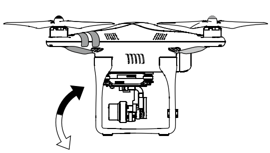
[5] Gimbal Dial

Use this dial to control the tilt of the gimbal.

Controlling Aircraft

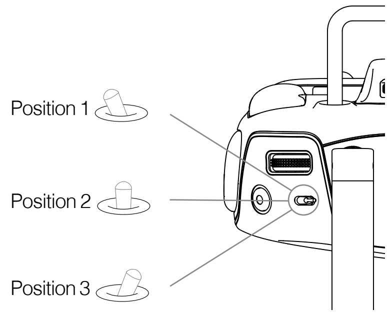
This section explains how to control the orientation of the aircraft through the remote controller. The Remote Control is set to Mode 2 by default.

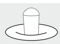
Stick Neutral/Mid-Point: Control sticks are in the center position.
Moving the Control Stick: The control stick is pushed away from the center position.

Remote Controller (Mode 2)	Aircraft (● Indicates Nose Direction)	Remarks
		Moving the left stick up and down changes the aircraft's elevation. Push the stick up to ascend and down to descend. When both sticks are centered, the Phantom 3 Advanced will hover in place. The more the stick is pushed away from the center position, the faster the Phantom 3 Advanced will change elevation. Always push the stick gently to prevent sudden and unexpected elevation changes.
		Moving the left stick to the left or right controls the rudder and rotation of the aircraft. Push the sick left to rotate the aircraft counter-clockwise, push the stick right to rotate the aircraft clockwise. If the stick is centered, the Phantom 3 Advanced will maintain its current orientation. The more the stick is pushed away from the center position, the faster the Phantom 3 Advanced will rotate.
		Moving the right stick up and down changes the aircraft's forward and backward pitch. Push the stick up to fly forward and down to fly backward. Phantom 3 Advanced will hover in place if the stick is centered. Push the stick further away from the center position for a larger pitch angle (maximum 30˚) and faster flight.
		Moving the right stick control left and right changes the aircraft's left and right pitch. Push left to fly left and right to fly right. The Phantom 3 Advanced will hover in place if the stick is centered.
		Gimbal Dial: Turn the dial to the right, and the camera will shift to point upwards. Turn the dial to the left, and the camera will shift to point downwards. The camera will remain in its current position when dial is static.

Flight Mode Switch

Toggle the switch to select the desired flight mode. You may choose between; P-mode, F-mode and A-mode.



Position	Figure	Flight Mode
Position 1		F-mode
Position 2		A-mode
Position 3		P-mode

P-mode (Positioning): P-mode works best when the GPS signal is strong. There are three different versions of P-mode, which will be automatically selected by the Phantom 3 Advanced depending on GPS signal strength and the Vision Positioning sensors:

P-GPS: GPS and Vision Positioning both are available; the aircraft is using GPS for positioning.

P-OPTI: Vision Positioning is available but a sufficient GPS signal is not available. Aircraft is using only Vision Positioning for position holding.

P-ATTI: Neither GPS nor Vision Positioning is available, the aircraft is using only its barometer for positioning, so only altitude is maintained.

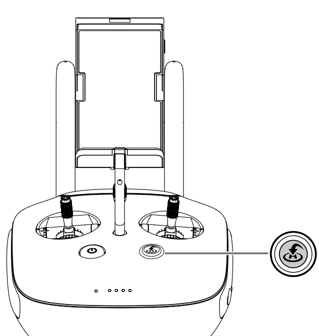
A-mode (Attitude): GPS and Vision Positioning System are not used for stabilization. The aircraft uses only its barometer to stabilize. The aircraft can automatically return to the Home Point if remote controller signal is lost and the Home Point was recorded successfully.

F-mode (Function): Intelligent Orientation Control (IOC) is activated in this mode. For more information about IOC, refer to the IOC section in the Appendix.

By default, the Flight Mode Switch is locked to P-mode. To unlock other flight modes, launch the DJI Pilot app, enter the “Camera” page, and tap “Mode”, then activate “Multiple Flight Mode”.

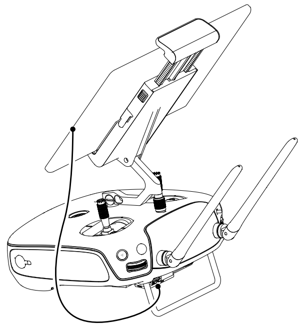
RTH Button

Press and hold the RTH button to start the Return-to-Home (RTH) procedure. The LED ring around the RTH Button will blink white to indicate that the aircraft is entering RTH mode. The aircraft will then return to the last recorded Home Point. Press this button again to cancel the RTH procedure and regain control of the aircraft.



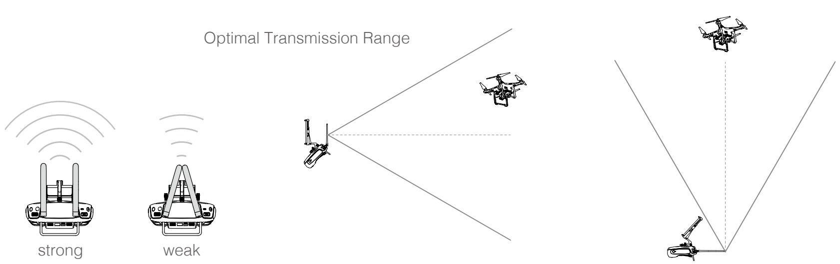
Connecting Your Mobile Device

Tilt the mobile device holder to the desired position. Press the button on the side of the mobile device holder to release the clamp, and then place your mobile device into the cradle. Adjust the clamp down to secure the mobile device. To connect your mobile device to the remote controller using a USB cable, plug one end of the cable into your mobile device and the other end into the USB port on the back of the remote controller.



Optimal Transmission Range

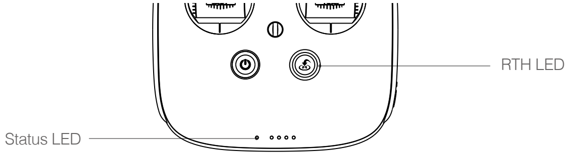
The transmission signal between the aircraft and the remote controller is most reliable within the area that is depicted in the image below:



Ensure that the aircraft is flying within the optimal transmission zone. To achieve the best transmission performance, maintain the appropriate relationship between the operator and the aircraft.

Remote Controller Status LED

The Status LED reflects the strength of the connection between the remote controller and the aircraft. The RTH LED indicates the Return-to-Home status of the aircraft. The table below contains more information about these indicators.



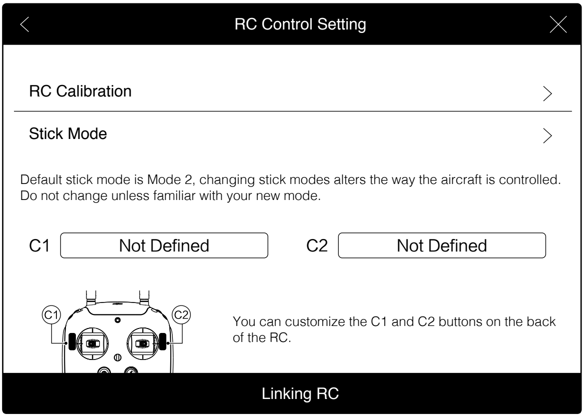
Status LED	Alarm	Remote Controller Status
R —— Solid Red	♪ Chime	The remote controller is disconnected from the aircraft.
G —— Solid Green	♪ Chime	The remote controller is connected to the aircraft.
R ······ Slow Blinking Red	D-D-D······	Remote controller error.
R G / R Y ······ Red and Green/ Red and Yellow Alternate Blinks	None	HD downlink is disrupted.
RTH LED	**Sound**	**Remote Controller Status**
W —— Solid White	♪ Chime	Aircraft is returning home.
W ······ Blinking White	D · · ·	Sending Return-to-Home command to the aircraft.
W ······ Blinking White	DD ·· ·· ··	Return-to-Home procedure in progress.

⚠ The Remote Status Indicator will blink red, sound an alert, when the battery level is critically low.

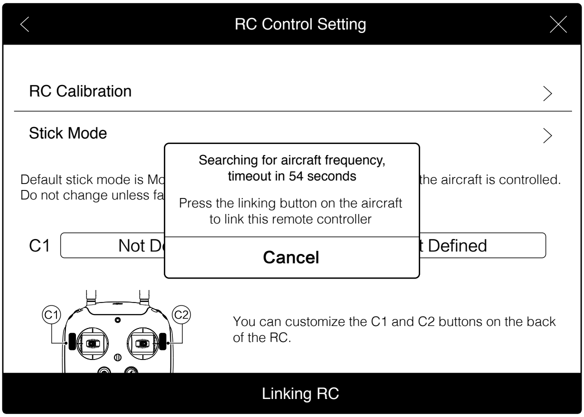
Linking the Remote Controller

The remote controller is linked to your aircraft before delivery. Linking is only required when using a new remote controller for the first time. Follow these steps to link a new remote controller:

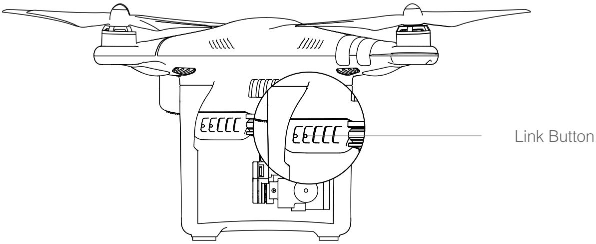
1. Turn on the remote controller and connect to the mobile device. Launch DJI Pilot app.
2. Turn on the Intelligent Flight Battery.
3. Enter "Camera" and tap on and then tap "Linking RC" button as shown below.



4. The remote controller is ready to link. The Remote Controller Status Indicator blinks blue and a beep is emitted.



5. Locate the linking button on the side of the aircraft, as shown in the figure shown below. Press the linking button to start linking. The Remote Controller Status Indicator will display solid green once the remote controller is successfully linked to the aircraft.



⚠ • The remote controller will un-link itself from an aircraft if a new remote controller is linked to the same aircraft.

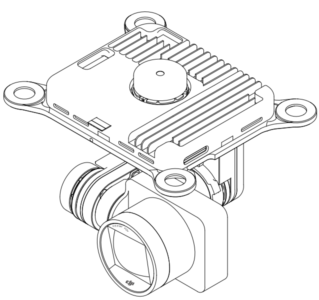
Remote Controller Compliance Version

The remote controller is compliant with both CE and FCC requirements.

Remote Controller

Camera and Gimbal

This section provides the technical specifications of the camera and explains the gimbal's operation modes.



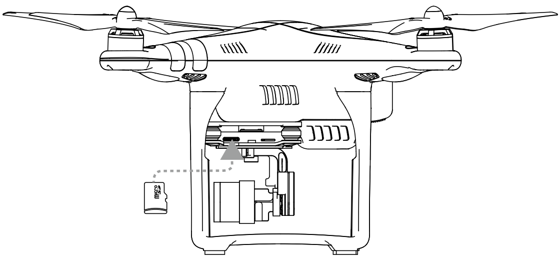
Camera and Gimbal

Camera Profile

The on-board camera uses the 1/2.3 inch CMOS sensor to capture video (up to1080p at 60 frames per second with the Phantom 3 Advanced) and 12 megapixel stills. You may export the video in either MOV or MP4 format. Available picture shooting modes include burst, continuous, and time-lapse mode. A live preview of what the camera sees can be monitored on the connected mobile device via the DJI Pilot app.

Camera Micro-SD Card Slot

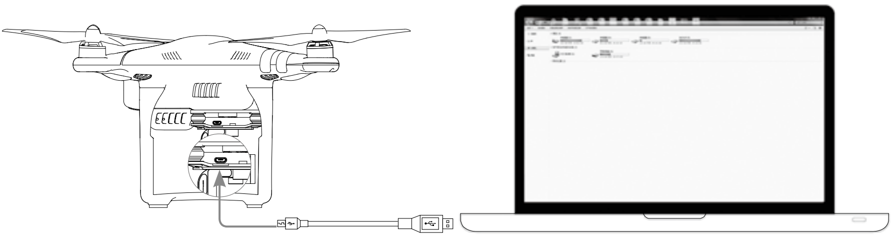
To store your photos and videos, insert the Micro-SD card into the slot, as shown below, before turning on the Phantom 3 Advanced. The Phantom 3 Advanced comes with a 16 GB Micro-SD card and supports Micro-SD cards up to 64 GB. A UHS-1 Micro-SD card is recommended due to their fast read and write time, which will allow you to save high-resolution video data.



⊘ Do not remove the Micro-SD card from the Phantom 3 Advanced when it is turned on.

Camera Data Port

Turn on the Phantom 3 Advanced and connect a USB cable to the Camera Data Port to download photos and videos to your computer.



⚠ Turn on the aircraft before attempting to access the files on the Micro-SD card.

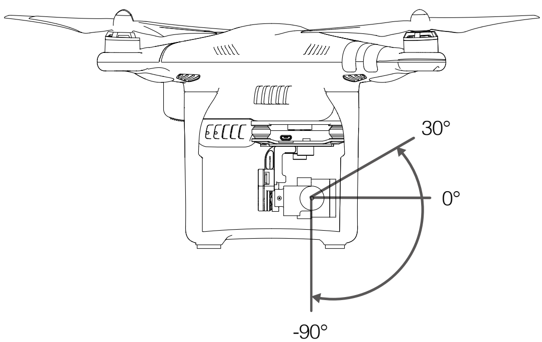
Camera Operation

Use the Shutter and Video Recording button on the remote controller to shoot the images or the videos through the DJI Pilot app. For more information about how to use these buttons, refer to “Controlling the Camera P24”.

Gimbal

Gimbal Profile

The 3-axis gimbal provides a steady platform for the attached camera, allowing you to capture clear, stable images and video. The gimbal can tilt the camera within a 120˚ range.



Use the gimbal dial on the remote controller to control the tilt movement of the camera.

Gimbal Operation Modes

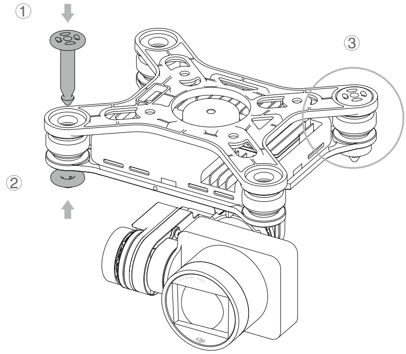
Two gimbal operation modes are available. Switch between the different operation modes on the camera settings page of the DJI Pilot app. Note that your mobile device must be connected to the remote controller for changes to take effect. Refer to the table below for details:

	Follow Mode	The angle between gimbal’s orientation and aircraft’s nose remains constant at all times.
	FPV Mode	The gimbal will synchronize with the movement of the aircraft to provide a first-person perspective flying experience.

- A gimbal motor error may occur in these situations: (1) the aircraft is placed on uneven ground or the gimbal’s motion is obstructed (2) the gimbal has been subjected to an excessive external force, such as a collision. Please take off from flat, open ground and protect the gimbal at all times.
- Flying in heavy fog or clouds may make the gimbal wet, leading to temporary failure. The gimbal will recover full functionality after it dries.

Anti-Drop Kit

The anti-drop kit helps keep the gimbal and camera connected to the aircraft. Two pins have been mounted prior to shipping. If new or additional pins are required, see the diagram below. Press Part ① through the hole of the vibration absorber and into the center hole of Part ② , then lock them together as shown ③ . Mounting the anti-drop kit pins diagonally from each other is recommended.

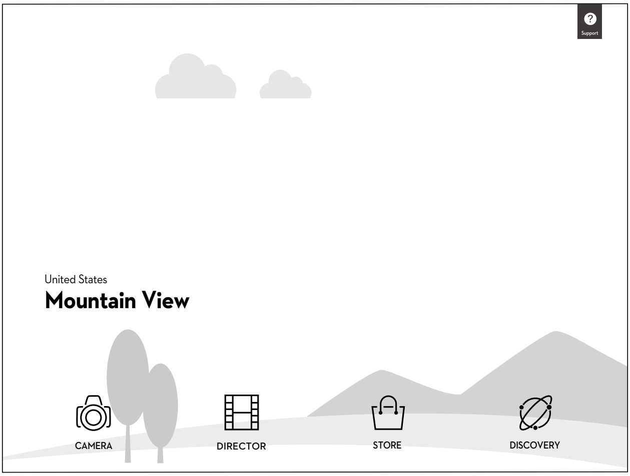


DJI Pilot App

This section introduces the four main functions of the DJI Pilot app.

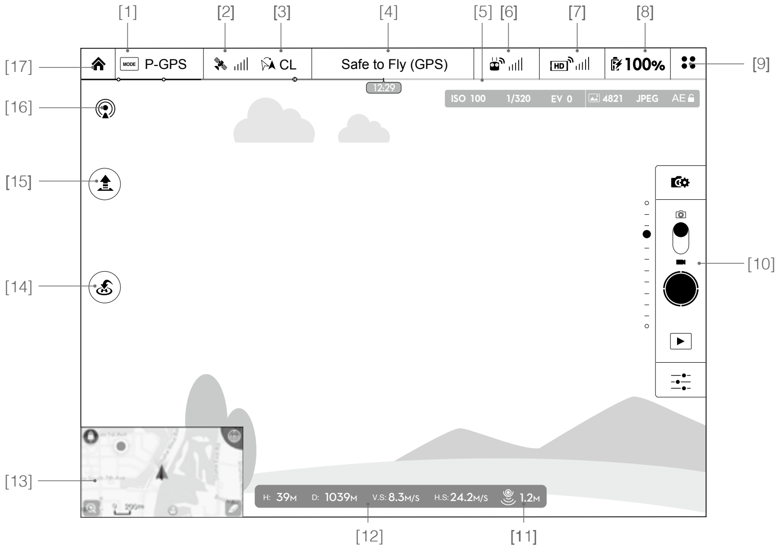
DJI Pilot App

The DJI Pilot app is a mobile application designed specifically for the Phantom 3 Advanced. Use this app to control the gimbal, camera, and other aircraft functions. The app also features Map, Academy, and User Center, which are used for configuring your aircraft and sharing your photos and videos with others. It is recommended that you use a tablet for the best experience.



Camera

The Camera page contains a live HD video feed from the Phantom 3 Advanced's camera. You can also configure various camera parameters from the Camera page.



[1] Flight Mode

MODE: The text next to this icon indicates the current flight mode.

Tap to configure the MC (Main Controller) Settings. These settings allow you to modify flight limits, perform compass calibration, and set the gain values.

[2] GPS Signal Strength

: This icon shows the current strength of GPS signals. Green bars indicates adequate GPS strength.

[3] IOC Settings

CL : This icon displays the IOC setting when the aircraft has entered F-mode. Tap to view the IOC settings menu and select the desired IOC setting.

[4] System Status

Safe to Fly (GPS) : This icon indicates the current aircraft system status and GPS signal strength.

[5] Battery Level Indicator

: The battery level indicator provides a dynamic display of the battery level. The colored zones on the battery level indicator represent the power levels needed to carry out different functions.

[6] Remote Controller Signal

: This icon shows the strength of remote controller signal.

[7] HD Video Link Signal Strength

HD: This icon shows the strength of the HD video downlink connection between the aircraft and the remote controller.

[8] Battery Level

100%: This icon shows the current battery level.

Tap to view the battery information menu, set the various battery warning thresholds, and view the battery warning history.

[9] General Settings

: Tap this icon to view the General Settings page. From this page, you can set flight parameters, reset the camera, enable the quick view feature, adjust the gimbal roll value, and toggle the flight route display.

[10] Camera Operation Bar

Shutter and Recording Settings

: Tap to enter various camera value settings, that including color space for the recording, size of the video files, image size and so on.

Shutter

: Tap this button to take a single photo. Press and hold this button to select single shooting, triple shot or time-lapsed shooting mode.

Record

: Tap once to start recording video, then tap again to stop recording. You can also press the Video Recording Button on the remote controller, which has the same function.

Playback

: Tap to enter playback page. You can preview photos and videos as soon as they are captured.

Camera Settings

: Tap to set ISO, shutter and auto exposure values of the camera.

[11] Vision Positioning

: This ic on shows the distance between the surface and the Vision Positioning System's sensors.

[12] Flight Telemetry

Vision Positioning Status icon is highlighted when Vision Positioning is in operation.

Flight attitude is indicated by the flight attitude icon.
(1) The red arrow shows which direction the aircraft is facing.
(2) Light blue and dark blue areas indicate pitch.
(3) The angle of the boundary between the light blue and dark blue areas indicates the roll angle.

[13] Map

Display the flight path of the current flight. Tap to switch from the Camera GUI to the Map GUI.

[14] Return to Home (RTH)

: Initiate RTH home procedure. Tap to have the aircraft return to the last recorded home point.

[15] Auto Takeoff/Landing

/ : Tap to initiate auto takeoff or landing.

[16] Livestream

: Livestream icon indicates the current video feed is broadcasting live on YouTube. Be sure the mobile data service is available on the mobile device.

[17] Back

: Tap to return to the main GUI.

Director

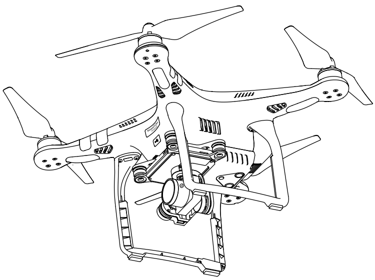
Director is an automatic video editor built into the DJI Pilot app. After recording several video clips, simply tap “Director” from the app’s home screen. You can then select a template and a specified number of clips, which are automatically combined to create a short film that can be shared immediately.

Store

Tap “Store” to visit the official DJI Online Store to see the latest information about DJI products and easily buy new products.

Discovery

Sync pictures and videos to your mobile device, view flight logs, and check your DJI account status in "Discovery". Use your registered DJI account to login to "Discovery".



Flight

This section describes safe flight practices and flight restrictions.

Flight

Once pre-flight preparation is complete, it is recommended that you use the flight simulator in the DJI Pilot app to hone your flight skills and practice flying safely. Ensure that all flights are carried out in an open area.

Flight Environment Requirements

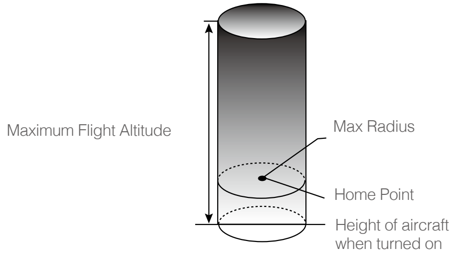
1. Do not use the aircraft in severe weather conditions. These include wind speed exceeding 10 m/s , snow, rain and smog.
2. Only fly in open areas. Tall structures and large metal structures may affect the accuracy of the on-board compass and GPS system.
3. Avoid obstacles, crowds, high voltage power lines, trees, and bodies of water.
4. Minimize interference by avoiding areas with high levels of electromagnetism, including base stations and radio transmission towers.
5. Aircraft and battery performance is subject to environmental factors such as air density and temperature.Be very careful when flying at altitudes greater than 19, 685 feet (6000 meters) above sea level, as the performance of the battery and aircraft may be affected.
6. The Phantom 3 Advanced cannot operate within the polar areas.

Flight Limits and No-Fly Zones

All unmanned aerial vehicle (UAV) operators should abide by all regulations set forth by government and regulatory agencies including the ICAO and the FAA. For safety reasons, flights are limited by default, which helps users operate this product safely and legally. Flight limitations include height limits, distance limits, and No-Fly Zones.
When operating in P-mode, height limits, distance limits, and No-Fly Zones function concurrently to manage flight safety. In A-mode, only height limits are in effect, which by default prevent the aircraft altitude from exceeding 1640 feet (500 m) .

Maximum flight altitude & Radius Limits

Maximum flight altitude and radius limits may be changed in the DJI Pilot app. Be aware that the maximum flight altitude cannot exceed 1640 feet (500 meters). In accordance with these settings, your Phantom 3 Advanced will fly in a restricted cylinder, as shown below:



GPS Signal Strong Ⓖ ······ Blinking Green			
	Flight Limits	DJI Pilot app	Aircraft Status Indicator
Maximum Flight Altitude	Aircraft's altitude cannot exceed the specified value.	Warning: Height limit reached.	None.
Max Radius	Flight distance must be within the max radius.	Warning: Distance limit reached.	Rapid red flashing Ⓡ ······ when close to the max radius limit.

GPS Signal Weak Ⓨ ······ Blinking Yellow			
	Flight Limits	DJI Pilot app	Aircraft Status Indicator
Maximum Flight Altitude	Height is restricted to 400 feet. (120m) and under.	Warning: Height limit reached.	None.
Max Radius	No limits		

⚠ • If you fly out of the limit, you can still control the Inspire, but cannot fly it any father.
• If the Inspire flies out of the max radius in Ready to Fly (non-GPS) mode, it will fly back within range automatically.

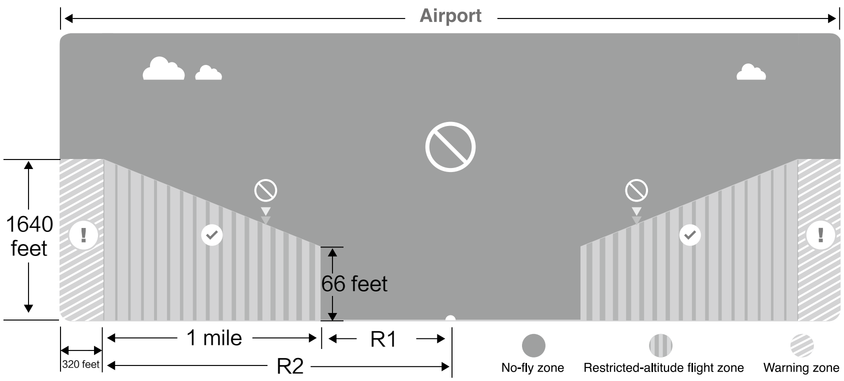
No-Fly Zones

All No-Fly Zones are listed on the DJI official website at http://flysafe.dji.com/no-fly. No-Fly Zones are divided into Airports and Restricted Areas. Airports include major airports and flying field where manned aircraft operate at low altitudes. Restricted Areas include border lines between countries or sensitive institute. The details of the No-Fly Zones are explained as follow:

Airport

(1) Airport No-Fly Zone are comprised of Take-off Restricted zones and Restricted -Altitude Zone. Each zone features circles of various size.
(2) R1 miles (value of the R1 depends on the size and shape of the airport) around the airport is Take-off restricted zone, inside of which take off is prevented.
(3) From R1 mile to R1 + 1 mile around the airport the flight altitude is limited on a 15 degree inclines. Starting at 65 feet (20 meters) from the edge of airport and radiate outward. The flight altitude is limited at 1640 feet (500 meters) at R1+1 mile
(4) When the aircraft enters within 320 feet (100 meters) of the No-Fly Zones, a warning message will prompt from the DJI Pilot app.

Flight

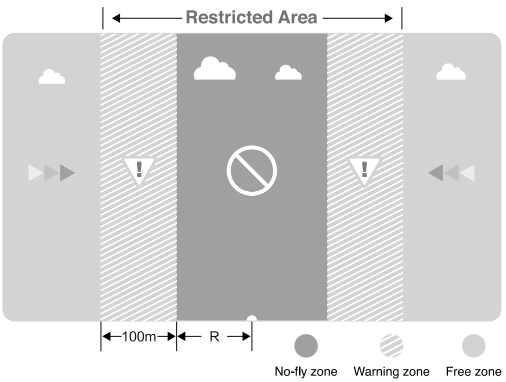


Restricted Area

(1) Restricted Area does not have flight altitude restriction.

(2) R miles around the designated restriction area is a Take-off Restricted area. Aircraft cannot take off within this zone. The value of R varies on the definition of the restricted areas.

(3) A “warning zone” has been set around the Restricted Area. When the aircraft approaches within 0.6 miles (1 km) of this zone, a warning message will prompt from the DJI Pilot app.



GPS Signal Strong	Ⓖ ······ Blinking Green		
Zone	Restriction	DJI Pilot App Prompt	Aircraft Status Indicator
No-fly Zone	Motors will not start.	Warning: You are in a No-fly zone. Take off prohibited.	Ⓡ ······ Red flashing
	If the aircraft enters the restricted area in A-mode, but is switched to P-mode, the aircraft will automatically descend, land, and stop its motors.	Warning: You are in a no-fly zone. Automatic landing has begun.	
Restricted-altitude flight zone	If the aircraft enters the restricted area in A-mode, but is switched to P-mode, it will descend to an appropriate altitude and hover 15 feet below the altitude limit.	R1: Warning: You are in a restricted zone. Descending to safe altitude. R2: Warning: You are in a restricted zone. Maximum flight altitude is restricted to between 20m and 500m. Fly cautiously.	
Warning zone	No flight restriction applies, but there will be a warning .	Warning: You are approaching a restricted zone, Fly Cautiously.	
Free zone	No restrictions.	None.	None.

Semi-automatic descent: All stick commands are available except the throttle stick command during the descent and landing process. Motors will stop automatically after landing.

- When flying in the safety zone, aircraft status indicator will blink red quickly and continue for 3 seconds, then switch to indicate current flying status and continue for 5 seconds at which point it will switch back to red blinking.
- For safety reasons, please do not fly close to airports, highways, railway stations, railway lines, city centers, or other sensitive areas. Fly the aircraft only within your line of sight.

Preflight Checklist

1. Remote controller, Intelligent Flight Battery, and mobile device are fully charged.
2. Propellers are mounted correctly and firmly.
3. Micro-SD card has been inserted, if necessary.
4. Gimbal is functioning normally.
5. Motors can start and are functioning normally.
6. The DJI Pilot app is successfully connected to the aircraft.

Calibrating the Compass

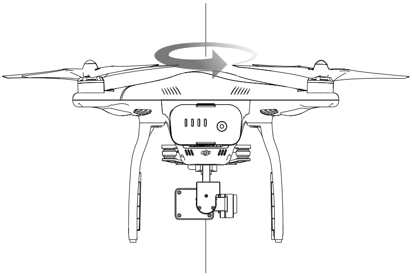
IMPORTANT: Always to calibrate the compass in every new flight location. The compass is very sensitive to electromagnetic interference, which can produce abnormal compass data and lead to poor flight performance or flight failure. Regular calibration is required for optimal performance.

- Do not calibrate your compass where there is any possibility of strong magnetic interference. Sources of potential interference include magnetite, parking structures, and subterranean metal structures
- Do not carry ferromagnetic materials with you during calibration such as keys or cellular phones.
- Do not calibrate in direct proximity to large metal objects.
- DO NOT calibrate indoors.

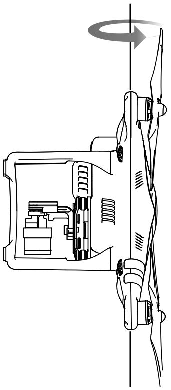
Calibration Procedures

Choose an open area to carry out the following procedures.

1. Ensure that the compass is calibrated. If you did not calibrate the compass as part of your pre-flight preparations, or if you have moved to a new location since the last calibration, tap “Mode” in the app and select “Compass Calibration”, then follow the on-screen instructions.
2. Hold the aircraft horizontally and rotate 360 degrees. The Aircraft Status Indicators will display a solid green light.



3. Hold the aircraft vertically, with nose pointing downward, and rotate it 360 degrees around the center axis. Recalibrate the compass if the Aircraft Status Indicator glows solid red.



⚠ If the Aircraft Status Indicator blinks red and yellow after the calibration procedure, move your aircraft to a different location and try again.

💡 Calibrate the compass before each flight. Launch DJI Pilot app and follow the on-screen instructions to calibrate the compass.

When to Recalibrate

1.When compass data is abnormal and the Aircraft Status Indicator is blinking green and yellow.
2.When flying in a new location or in a location that is different from the most recent flight.
3.When the mechanical or physical structure of the Phantom 3 Advanced has been changed.
4.When severe drifting occurs in flight, i.e. Phantom 3 Advanced does not fly in straight line.

Auto Takeoff and Auto Landing

Auto Takeoff

Use auto takeoff only if the Aircraft Status Indicators are blinking green. Follow the steps below to use the auto takeoff feature:

1. Launch the DJI Pilot app, and enter “Camera” page.
2. Ensure the aircraft is in P- mode.
3. Complete all steps on the pre-flight checklist.
4. Tap“⏏”, and confirm that conditions are safe for flight. Slide the icon to confirm and takeoff.
5. Aircraft takes off and hovers at (1.5 meters) above ground.

⚠ Aircraft Status Indicator blinks rapidly when it is using Vision Position System for stabilization. Aircraft will automatically hover below 3 meters. It is recommended to wait until there is sufficient GPS lock before using the Auto Take-off feature.

Auto-Landing

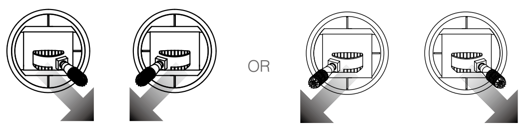
Use auto-landing only if the Aircraft Status Indicators are blinking green. Follow the steps below to use the auto-landing feature:

1. Ensure the aircraft is in P- mode.
2. Check the landing area condition before tapping “⤓”, to begin landing.

Starting/Stopping the Motors

Starting the Motors

A Combination Stick Command (CSC) is used to start the motors. Push both sticks to the bottom inner or outter corners to start the motors. Once the motors have started spinning, release both sticks simultaneously.

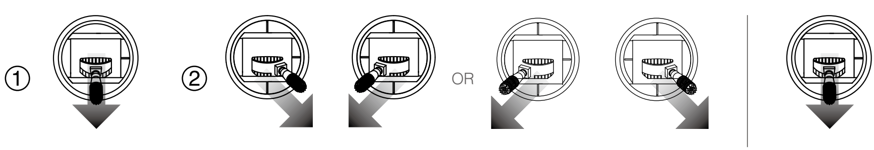


Stopping the Motors

There are two methods to stop the motors.

Method 1: When Phantom 3 Advanced has landed, push the throttle down①, then conduct the same CSC that was used to start the motors, as described above②. Motors will stop immediately. Release both sticks once motors stop.

Method 2: When the aircraft has landed, push and hold the throttle down. The motors will stop after three seconds.



Method 1 Method 2

⚠ Do not perform CSC when aircraft is in midair, otherwise the motors will be stopped.

Flight Test

Takeoff/Landing Procedures

1. Place the aircraft in an open, flat area with the battery level indicators facing towards you.
2. Turn on the remote controller and your mobile device, then the Intelligent Flight Battery.
3. Launch the DJI Pilot app and enter the Camera page.
4. Wait until the Aircraft Indicators blink green. This means the Home Point is recorded and it is now safe to fly. If they flash yellow, the Home Point has not been recorded.
5. Push the throttle up slowly to take off or use Auto Takeoff.
6. Shoot photos and videos using the DJI Pilot app.
7. To land, hover over a level surface and gently pull down on the throttle descend.
8. After landing, execute the CSC command or hold the throttle at its lowest position until the motors stop.
9. Turn off the Intelligent Flight Battery first, then the Remote Controller.

- When the Aircraft Status Indicators blink yellow rapidly during flight, the aircraft has entered Failsafe mode.
- A low battery level warning is indicated by the Aircraft Status Indicators blinking red slowly or rapidly during flight.
- Watch our video tutorials for more flight information.

Video Suggestions and Tips

1. Go through the full pre-flight checklist before each flight.
2. Select the desired gimbal operation mode in the DJI Pilot app.
3. Only shoot video when flying in P-mode.
4. Always fly in good weather and avoid flying in rain or heavy wind.
5. Choose the camera settings that suit your needs. Settings include photo format and exposure compensation.
6. Perform flight tests to establish flight routes and preview scenes.
7. Push the control sticks gently to keep the aircraft's movement stable and smooth.

FAQ

Troubleshooting (FAQ)

What is the difference between the Phantom 3 Professional and the Phantom 3 Advanced?

The biggest difference between the Phantom 3 Professional and the Phantom 3 Advanced is in the camera. The Phantom 3 Professional is capable of shooting spectacular 4K video at up to 30 frames per second, and the Phantom 3 Advanced is capable of shooting at resolutions up to 1080p60. Both models shoot 12 megapixel photos.

The other main difference is the Intelligent Flight Battery charger. The Phantom 3 Advanced comes with a 57-watt charging unit and the Phantom 3 Professional comes with a 100-watt charger, the latter of which allows for shorter charging times.

Can I remove the camera and attach my own?

No. The cameras that come with both models are permanently attached. Attempting to remove, replace, or modify the camera may damage the product and will void your warranty.

Can I charge my Remote Controller and Intelligent Flight Battery at the same time?

While the Remote Controller charger and Intelligent Flight Battery charger have been integrated into one unit for your convenience, it is recommended that you only charge one item at a time. We recommend that you never charge both items using the same charger at the same time.

What are the buttons on the back of my Remote Controller for?

The two buttons on the back of the Remote Controller can be customized and assigned to function as you choose through the DJI Pilot app. Refer to the manual for more information.

How far can I fly my Phantom 3?

The signal transmission distance will vary depending on environmental conditions, but the Phantom 3 series can reach distances of up to 1.2 miles (2 kilometers) away from the pilot.

What app should I use with my Phantom 3?

The Phantom 3 is compatible with the DJI Pilot app for iOS and Android, which is already used with the DJI Inspire 1. The app will detect which aircraft is connected and automatically adjust accordingly.

Which mobile devices are compatible with the app?

The DJI Pilot app is only compatible with devices running iOS 8.0 or later or Android v4.1.2 or later.

The following devices are recommended:

iOS: iPhone 5s, iPhone 6, iPhone 6 Plus, iPad Air, iPad Air Wi-Fi + Cellular, iPad mini 2, iPad mini 2 Wi-Fi + Cellular, iPad Air 2, iPad Air 2 Wi-Fi + Cellular, iPad mini 3, and iPad mini 3 Wi-Fi + Cellular. This app is optimized for iPhone 5s, iPhone 6, and iPhone 6 Plus

Android: Samsung S5, Note 3, Sony Z3 EXPERIA, Google Nexus 7 II, Google Nexus 9, Mi 3, Nubia Z7 mini

Support for additional Android devices will become available as testing and development continues.

How do I use the Director automatic video editor?

Director is an automatic video editor built into the DJI Pilot app. After recording several video clips, simply tap "Director" from the app's home screen. You can then select a template and a specified number of clips, which are automatically combined to create a short film that can be shared immediately.

How do I change the control mode of my Phantom 3?

By default, the Remote Controller is set to Mode 2. This means that the right control stick controls the movement of the aircraft and the left control stick controls the throttle and orientation of the aircraft. These controls can be changed to Mode 1 or set to a customized configuration in the DJI Pilot app. This is only recommended for advanced users.

Can I use a Phantom 2 Remote Controller with the Phantom 3?

No. The Phantom 2 Remote Controller operates on a different frequency. The Phantom 2 Remote Controller operates at 5.8 GHz and the new Phantom 3 Remote Controller operates at 2.4 GHz.

Can I use a Phantom 2 Intelligent Flight Battery with the Phantom 3?

No. The Phantom 3 uses a newly designed Intelligent Flight Battery with greater power. The Phantom 3 has a 4 cell battery with a capacity of 4480 mAh and a voltage of 15.2 V.

My Phantom 3 does not turn off right away, is something wrong?

This is normal. After you attempt to power off the Intelligent Flight Battery, it may remain on for a few seconds as any video data is saved to the Micro SD card. This helps prevent your data from being lost or corrupted.

Do I have to buy the Remote Controller separately?

No, there is no need to buy a separate Remote Controller. Your Phantom 3 comes with a Remote Controller that is already linked to the aircraft.

Does my Phantom 3 support dual Remote Controllers?

No. The included Remote Controller can be used to control both the aircraft and the gimbal tilt at the same time.

What does the "P, A, F" switch on the Remote Controller do?

This switch, called the Flight Mode Switch, allows you to toggle different flight modes:

P-mode, or Positioning mode, indicates that both GPS and the Vision Positioning System are active and your Phantom 3 will attempt to stabilize using both.

In A-mode, or Attitude mode, the aircraft does not use GPS or the Vision Positioning System. Only the barometer is used for stabilization. The aircraft can still return to the Home Point as long as a sufficient GPS signal is available.

F-mode, or Function mode, activates Intelligent Orientation Control (IOC) functionality. Refer to the IOC section in the Appendix of the User Manual.

By default, only P-mode may be used. Refer to your user manual for instructions on unlocking the other modes.

What is the Phantom 3 flight time?

Flight times will vary depending on environmental conditions and usage patterns, but the Intelligent Flight Battery is designed to provide up to 23 minutes of uninterrupted flight time when fully charged.

How can I restore a video file if the power is turned off during recording?

Do not remove the Micro-SD card from the camera. If it has been removed, place it back in the camera. Turn the Phantom 3 on and wait approximately 30 seconds as the video file is restored.

How can I ensure that my pictures and videos will be synchronized to my iOS album?

You may need to adjust the settings of your mobile device. Open the Settings menu, select the Privacy tab, select the Photos tab, and then toggle the switch next to the DJI Pilot app icon. If the Pilot app has not been granted access to your albums, the photos and videos cannot be synchronized.

What should I do to land my Phantom 3 smoothly as possible?

Hover the aircraft over a flat, level surface. Slowly pull the throttle stick down until the aircraft touches the ground.

Why is the discharge time of the battery not zero, even though I have never used it?

Every battery is tested prior to being packaged and shipped. This affects the discharge time of a new battery and is the reason that the discharge time is not zero. The battery is safe to use.

Can the mobile device holder be used on the Phantom 2 series Remote Controller?

No, it cannot.

How to safely operate the aircraft when encountering compass error?

Compass error may occur when the aircraft is flying close to the strong electric magnetic sources (e.g. power transmission lines). Aircraft Status Indicators blink red and yellow rapidly when compass error occurs and DJI Pilot app will display the one of the following messages:

- Compass error, calibration required

  This warning message indicates the aircraft receives abnormal compass readings. It is power off the aircraft and re-calibrate the compass at the different location and resume the flight.
- Compass error, exit P-GPS Mode

  This warning message indicates that the aircraft is drifting severely. Bring the aircraft to a higher altitude to gain enough GPS locks when this warning message is prompted. The flight controller will automatically adjust the orientation of the aircraft in the midair to mitigate the drifts. Aircraft will switch back to P-GPS mode when the adjustment is done.

Appendix

Appendix

Specifications

Aircraft	
Weight (Battery & Propellers Included)	1280 g
Max. Ascent Speed	5 m/s
Max. Descent Speed	3 m/s
Max. Speed	16 m/s (ATTI mode, no wind)
Max. Flight Altitude	6000 m
Max. Flight Time	Approximately 23 minutes
Operating Temperature	0°C to 40°C
GPS Mode	GPS/GLONASS
Gimbal	
Controllable Range	Pitch: - 90° to + 30°
Vision Positioning	
Velocity Range	< 8 m/s (2 m above ground)
Altitude Range	30 cm-300 cm
Operating Range	30 cm-300 cm
Operating Environment	Brightly lit (lux > 15) patterned surfaces
Camera	
Sensor	Sony EXMOR 1/2.3” Effective pixels:12.4 M (total pixels: 12.76 M)
Lens	FOV 94° 20mm(35mm format equivalent) f/2.8
ISO Range	100-3200(video) 100-1600(photo)
Electronic Shutter Speed	8s -1/8000s
Image Max. Size	4000 x 3000
Still Photography Modes	Single shoot Burst shooting: 3/5/7 frames Auto Exposure Bracketing (AEB): 3/5 bracketed frames at 0.7EV Bias Time-lapse
Supported SD Card Types	Micro SD Max. capacity: 64 GB. Class 10 or UHS-1 rating required
Video Recording Modes	FHD:1920x1080p 24/25/30/48/50/60 HD:1280x720p 24/25/30/48/50/60
Max. Bitrate Of Video Storage	60 Mbps
Supported File Formats	FAT32/exFAT Photo: JPEG, DNG Video: MP4/MOV (MPEG-4 AVC/H.264)
Operating Temperature Range	0°C to 40°C

Remote Controller	
Operating Frequency	2.400 GHz-2.483 GHz
Transmitting Distance	2000 m (Outdoor And Unobstructed)
Video Output Port	USB
Operating Temperature Range	0°C- 40°C
Battery	6000 mAh LiPo 2S
Mobile Device Holder	Tablets and smartphones
Transmitter Power(EIRP)	FCC: 20 dbm; CE:16 dbm
Working Voltage	1.2 A @7.4 V
Charger	
Voltage	17.4 V
Rated Power	57 W
Intelligent Flight Battery (PH3-4480 mAh-15.2 V)	
Capacity	4480 mAh
Voltage	15.2 V
Battery Type	LiPo 4S
Energy	68 Wh
Net Weight	365 g
Operating Temperature	-10°C- 40°C
Max. Charging Power	100 W

Aircraft Status Indicator Description

Normal	
R G Y ······ Red, Green and Yellow Flash Alternatively	Turning on and Self-Checking
G Y ······ Green and Yellow Flash Alternatively	Aircraft Warming Up
G ······ Green Flashes Slowly	Safe to Fly (P-mode with GPS and Vision Positioning)
G X2 ······ Green Flashes Twice	Safe to Fly (P-mode with Vision Positioning but without GPS)
Y ······ Yellow Flashes Slowly	Safe to Fly (A-mode but No GPS and Vision Positioning)
Warning	
Y ······ Fast Yellow Flashing	Remote Controller Signal Lost
R ······ Slow Red Flashing	Low Battery Warning
R ······ Fast Red Flashing	Critical Battery Warning
R ······ Red Flashing Alternatively	IMU Error
R —— Solid Red	Critical Error
R Y ······ Red and Yellow Flash Alternatively	Compass Calibration Required

Intelligent Orientation Control (IOC)

IOC allows users to lock the control orientation of aircraft in different modes. There are three working modes for IOC that can be selected in the DJI Pilot app. IOC only works when the aircraft is in F-mode, therefore the user must toggle the flight mode switch to activate IOC. Refer to the table below:

Course Lock (CL)	The nose direction, at the time that CL is set, will remain the forward direction regardless of how the orientation and position of the aircraft changes. This will remain fixed until you reset it or exit CL mode.
Home Lock (HL)*	Record a Home Point (HP) and enter HL mode. The forward and backward controls will move the aircraft farther from and closer to the established Home Pont, regardless of how the orientation and position of the aircraft changes.
Point of Interest (POI)*	Point of Interest. Record a point of interest (POI). The aircraft can then circle around the POI and the nose will always points toward the POI.

*Home Lock and Point of Interest feature are coming soon.

IOC Requirements

IOC is only available under the following conditions:

Modes IOC	GPS enabled	GPS counts	Flight Distance Limits
Course Lock	No	None	None
Home Lock	Yes		Aircraft $\xleftrightarrow{\geq 10m}$ Home Point
POI	Yes		Aircraft $\xleftrightarrow{5m\sim500m}$ Point of Interest

Using IOC

Toggle the Flight Mode Switch F-mode and follow the instructions prompted on the DJI Pilot app to select the desired IOC mode.

FCC Compliance

FCC Compliance

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions:

(1) This device may not cause harmful interference, and

(2) This device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly roved by the party responsible for compliance could void the user's authority to operate the equipment.

Compliance Information

FCC Warning Message

Any Changes or modifications not expressly roved by the party responsible for compliance could void the user's authority to operate the equipment.

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

FCC Radiation Exposure Statement:

This equipment complies with FCC radiation exposure limits set forth for an uncontrolled environment. This equipment should be installed and operated with minimum distance 20cm between the radiator& your body. This transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.

Note: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

—Reorient or relocate the receiving antenna.

—Increase the separation between the equipment and receiver.

—Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.

—Consult the dealer or an experienced radio/TV technician for help.

IC RSS warning

This device complies with Industry Canada licence-exempt RSS standard (s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference,including interference that may cause undesired operation of the device.

Le présent areil est conforme aux CNR d'Industrie Canada licables aux areils radio exempts de licence.

L'exploitation est autorisée aux deux conditions suivantes:

(1) l'areil ne doit pas produire de brouillage, et

(2) l'utilisateur de l'areil doit accepter tout brouillage radioélectrique subi, même si le brouillage est

susceptible d'en compromettre le fonctionnement.

IC Radiation Exposure Statement:

This equipment complies with IC RF radiation exposure limits set forth for an uncontrolled environment. This transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.
This equipment should be installed and operated with minimum distance 20cm between the radiator& your body.
Any Changes or modifications not expressly roved by the party responsible for compliance could void the user's authority to operate the equipment.

KCC Warning Message

"해당무선설비는 운용 중 전파혼신 가능성이 있으므로 인명안전과 관련된 서비스는 할 수 없습니다 ."
"해당 무선설비는 운용 중 전파혼신 가능성이 있음"

NCC Warning Message

低功率電波輻射性電機管理辦法
第十二條經型式認證合格之低功率射頻電機，非經許可，公司、商號或使用者均不得擅自變更頻率、加大功率或變更原設計之特性及功能。
第十四條低功率射頻電機之使用不得影響飛航安全及干擾合法通信；經發現有干擾現象時，應改善至無干擾時方得繼續使用。前項合法通信，指依電信法規定作業之無線電通信。低功率射頻電機須忍受合法通信或工業、科學及醫療用電波輻射性電機設備之干擾。

The content is subject to change.

Download the latest version from
http://www.dji.com/phantom3

If you have any questions about this document, please contact DJI by sending a message to **DocSupport@dji.com**.

GCI-G1536F

FOR A GOOD REASON GRUNDIG

5 MP 360° Fisheye IP Camera ICR IR LED

- 360° field of view
- 5 Megapixels CMOS, Colour/B&W Camera
- IR LEDs integrated
- ONVIF Profile S compliant for maximum compatibility with VMS
- H.264 & MJPEG compression modes (max. 30/25 fps)
- SDHC memory card slot for alarm and schedule image recording

Summary

Grundig’s extensive, new IP CCTV surveillance range offers an outstanding video security solution and is designed to meet every current surveillance requirement. Grundig has embraced the latest IP technology to create a range with impressive functionality and quality.
The new Grundig IP cameras are designed to suit every environment, however hostile or challenging. The new IP camera range includes PTZ and vandal-resistant domes for internal and external applications, traditional box cameras and specialist designs for specific application requirements. Further practical installation features include weather-resistance, a variety of mounting methods and comprehensive integration and compatibility.
Each camera offers advanced specifications, making effective use of the latest IP CCTV technologies. These include high resolutions providing clear images for detailed identification and evidential purposes a variety of exposure methods and encrypted recording directly onto a SD card. Intelligent features include privacy zones for non-invasive surveillance and legal compliance intelligent alerts to operators and system management tools using motion detection and other alarm triggers.
Each camera comes with full ONVIF support to ensure full integration and future-proofing.
German video security excellence - by GRUNDIG

AASSET SECURITY GmbH - Max-Planck-Str. 15 a-c - D 40699 Erkrath - Deutschland
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GCI-G1536F

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Technical Specifications

Image Sensor	1/2.5" CMOS 5.0 Megapixel
Pixels - Total	2592 (H) x 1944 (V)
Digital Signal Processor (DSP)	Ambarella A5S
Sensitivity Colour	0.2 Lux @ F2.8
Sensitivity B/W	0.02 Lux @ F2.8
Col/B&W	On/Off/SMART, IR-cut filter removable (ICR)
Lens Focal Length	1.05 mm
Viewing Angle	180° circle (full hemisphere)
Digital Zoom	Off ~ 8x
Iris F-Number	F 2.8
Lens Drive Type	Fixed Iris
IR LED	6 pieces
Max. IR Distance	Ø 6 m @ 3m
Wavelength	850nm
Shutter Speed	1 ~ 1/10.000 sec
PTZ Control	digital Pan/Tilt/Zoom
WDR	Off/Low/Middle/High
BLC Back Light	On/Off
White Balance	ATW, AWB, Manual, Push, ATW, AWB, Manual, One Push
Privacy zones	5 zones, rectangle
Privacy Zone Type:	rectangle, Color selection
Alarm Trigger	Alarm Input, Motion Detection, Network Failure detection, Tampering Alarm, Time lapse, Manual Trigger, Audio detection
Motion Detection	On, Off, by Schedule
Tampering Alarm	On, Off, by Schedule
Time Lapse	Off, On (60~3600s)
Manual Trigger	On, Off
Audio detection	Off, On
Schedule	Single Day or Week, Time (Start, Duration), DAY or NIGHT Mode
Reverse	Normal, Flip, Mirror, Vertical Mode (90°clockwise,90° counter clockwise), 180°

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Technical Specifications

Digital Noise Reduction (DNR)	3DNR (Off,Low,Mid,Hi), 2DNR (Off,On), Color NR (Off,Low,Mid,Hi)
Camera ID	20 character
Video Text Overlay	Text string (20 character), Subtitel (5 lines @ 16 character)
D&N Switching Mode:	Light Sensor (Auto with LED), Light ON, Light OFF, SMART, Auto, Night, Day
Alarm Event	Enable Alarm Output, Send message by FTP or/and Email, Upload image by FTP or/and Email, Send HTTP notification, IR CUT filter switch On/Off, Record to Micro SD Card
Access protection	By log-in and Password, IP filter, IEEE802.1x
Number of Clients	Up to 20 simultaneously
Video Compression	H.264 (MPEG-4Part 10/AVC), MJPEG
ONVIF compliant	Profile S
Video Streaming	Quad stream: 4xH.264 or 3xH.264+MJPEGTriple: 3xH.264 or 2xH.264+MJPEGDual: 2xH.264 or H.264+MJPEGSingle: H.264 or MJPEG
Video Resolution	5MP(2592x1944)/3MP(2048x1536)/Full HD 1080p/SXGA/HD 720p/XGA/SVGA/4CIF/VGA/CIF
Frame Rate (Max@Resolution)	12fps@5MP, 15fps@3MP, 25fps@2MP, 25fps@1,3MP, etc.
Streaming Method	Unicast, Multicast
Audio Compression	G.726, G.711
Audio Communication	Bi-directional
Audio Input/Output	built in Microphone and loudspeaker, over an optional "all in one cable" Line In/Out
Alarm Inputs	1x (5V, 10KOhms)
Alarm Outputs	1 (max.300VDC/AC, 39W), 1 (max.300VDC/AC, max.130mA)
Recording at the Edge:	supports up to 64GB capacity Micro SD/SDHC/SDXC Card
SD memory	supports up to 64 GB capacity of micro SD/SDHC/SDXC memory, supports up to 32 GB capacity of micro SD/SDHC memory
Recording Types:	on Micro SD/SDHC CARD:Single Image Recording (JPEG), Video(AVI, LCK) on NAS: Video (AVI)
NAS Recording:	Yes

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Technical Specifications

Web Browser	MS Internet Explorer 6.0 (or higher), Firefox, Google Chrome, Safari
Network Protocol	IPv4/v6, TCP/IP, UDP, RTP, RTSP, HTTP, HTTPS, DHCP, PPPoE, UPnP, SMTP, ICMP, IGMP, SNMP, IEEE802.1x, QoS, ONVIF, FTP, ARP
Firmware Upgrade	by Web Browser or Grundig finder (from ver.1.17)
Configuration	by web interface
Multi Language Webpage:	English, German, French, Italian, Russian, Turkish
LED Indicator	Power, link, active
Operating Temperature	-10°C ~ +50°C
Humidity	10 ~ 90% no condensation
Regulation	CE, FCC, RoHS Compliant
Supply Voltage	24 Vac / 12 Vdc / PoE (IEEE 802.3af)
Input/Output sockets	Power (Terminal 3-Pin), RJ-45, Micro SD/SDHC Card Slot, 8-Pin Connector(4-Pin Alarm IN/OUT,,Audio IN/OUT (2xMicro Jack)
Recording	H.264
Lens	
Illuminator	:
Audio Inputs	1x 3.5mm jack + 1x Microphone built-in
Audio Outputs	1x 3.5mm jack (Line), 1x loudspeaker
Operating Humidity	10% ~ 90%, non-condensing
Power Consumption (W)	8
Weight	0.35 kg - 0.77 lbs

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Accessories

GAC-C2030A
Optional cable for Fisheye Cameras

GCI-G1536F

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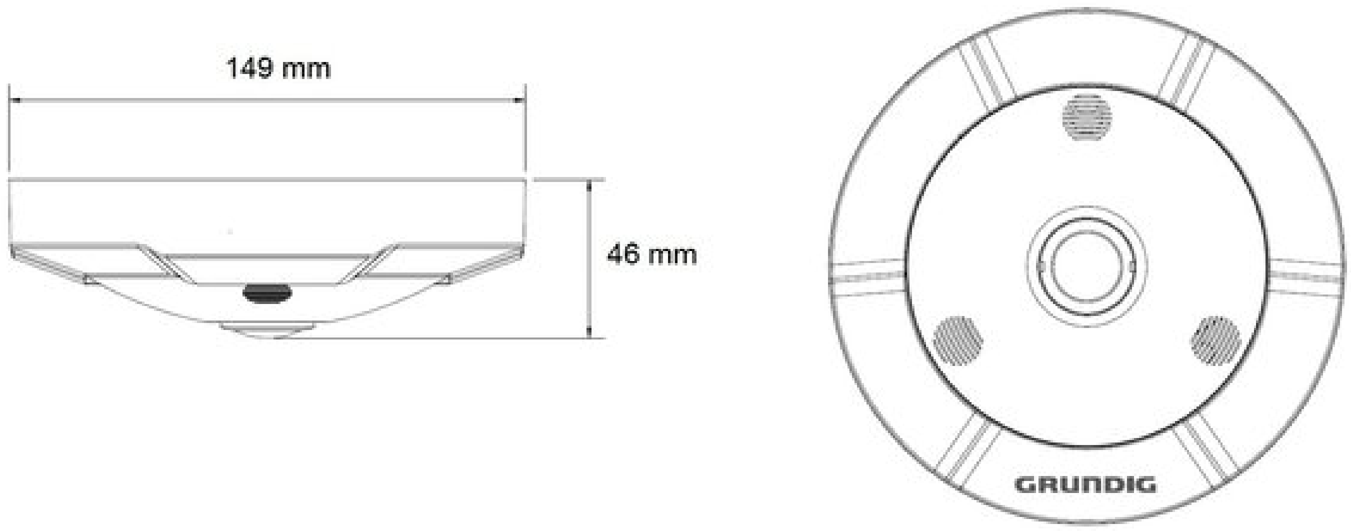
Dimensions



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Dell Latitude 7000 Series

The commercial laptop completely redefined — amazing looks, leading reliability and Ultrabook™ mobility

Elite design and reliability

The thin, lightweight Latitude 7000 Series Ultrabooks offer mobility at its finest, with the 12-inch model starting at just 20mm thin and 1.3 kg (2.99 lbs) with a 3-cell battery[1].

Strong and beautiful, the non-touch screen models feature durable aluminium design with a soft-touch paint finish. The touch-screen option[2] is wrapped in strong, attractive woven carbon fiber for added durability.

Intel® Core i™ ultra-low voltage processors and a choice of solid state drives or performance solid state hybrid drives also deliver reliable mobile productivity.

Like all Latitude laptops, Latitude 7000 Series Ultrabooks are subject to MIL-STD 810G testing and endure "highly-accelerated life tests" to ensure their durability. Latitude E-Family laptops are tested to survive an equivalent of 120 hours within a car in direct sunlight during summer, opening and closing every 15 minutes during work hours, and much more.

Consumer-inspired features

The option of a touch screen in a full laptop is noteworthy, offering an outstanding productivity experience with Genuine Windows 8 or Genuine Windows 8 Pro. The optional backlit keyboard makes it easy to type in dark environments.

The Latitude 7000 Series Ultrabooks also feature integrated Intel® Wireless Display (WiDi)[4]. WiDi allows a portable device or computer to send up to 1080p high-definition video and 5.1 surround sound to a compatible display wirelessly.

Dell Latitude 7000 Series is the only Ultrabook designed to be compatible with an existing laptop family docking station, as well as WiGig wireless docking (Dell Wireless Dock D5000) for easy integration into a desktop or conference room environment. Complete your docking solution with Dell UltraSharp monitors, Dell's wireless keyboard and mouse. Connect and collaborate effectively with broad connectivity options, an integrated HD webcam and microphone array.

On the go, easily transport your Ultrabook with Dell's Executive Leather Carrying Case, and the Latitude 7000 Series' swappable battery capability, along with the Dell 90-watt Auto/Air Charger with Power Cord, keeps you powered throughout the day.

The most secure Ultrabooks

With best-in-class endpoint security solutions that include comprehensive encryption, advanced authentication and leading-edge malware protection from a single source, the Latitude 7000 Series are the world's most secure Ultrabooks.

Protect data on any device, across external media and in the cloud with Dell Data Protection | Encryption. Dell Data Protection | Security Tools enables multifactor, single sign-on and preboot authentication along with integrated management with your encryption policies. Dell Latitude 7000 Series provides a FIPS 140-2-certified TPM, and Dell ControlVault adds another layer of hardware security by isolating user credentials on a separately controlled hardware chip.

Stop advanced malware in its tracks with Dell Data Protection | Protected Workspace, a proactive approach to malware protection that automatically detects and blocks all malicious behavior in real time — even zero-day attacks.

The most manageable business laptops

Easily manage your Latitude fleet with exclusive automated tools that plug into Microsoft System Center and Dell KACE.

Remotely manage your Latitude laptops with Intel® vPro™ technology and update once and everywhere with Dell-unique Intel vPro extensions for remote BIOS management and hard drive wipe, even when systems are powered off.

Create a standardized environment and simplify deployments with long lifecycles, Dell ProSupport[5], Dell Configuration and Deployment Services, and Dell Imaging Services.

Feature	Technical Specification	
Model Number	**Latitude 12 7000 Series (Model E7240)**	**Latitude 14 7000 Series (Model E7440)**
Processor Options	4th Generation Intel® Core™ processors up to i7	
Operating System Options	Genuine Windows® 7 Genuine Windows® 8 Genuine Windows® 8 Pro Linux Ubuntu 12.04	
Memory[6] Options	DDR3L SDRAM 1600MHz 2 slots supporting 1G, 2G, 4GB[7], 8GB DIMMs	DDR3 SDRAM 1600MHz 2 slots supporting 1G, 2G, 4GB[7], 8GB DIMMs
Chipset	Integrated with the CPU (Lynx Point-LP)	
Intel Responsiveness Technologies	Optional Intel® Rapid Start Technology[8] Optional Intel® Smart Connect Technology[9] (Require mobile solid state drive)	
Graphics[6] Options	Intel® Integrated HD Graphics up to 4400	
Display Options	12.5" HD (1366x768) Anti-Glare LED-backlit 12.5" FHD (1920x1080) Touch	14.0" HD (1366x768) Anti-Glare LED-backlit 14.0" FHD (1920x1080) Anti-Glare LED-backlit 14.0" FHD (1920x1080) Touch
Storage Options	Mobility Solid State up to 256GB[6] Dell Fast Response Free Fall Sensor and HDD Isolation (standard on the motherboard)	5400RPM SATA up to 500GB[6] Mobility Solid State up to 256GB[6] Dell Fast Response Free Fall Sensor and HDD Isolation (standard on the motherboard)
Optical Drive Options	N/A	N/A
Multimedia	High Quality Speakers Stereo global headset jack Integrated, noise reducing array microphones Optional Integrated HD video webcam and Dell Webcam Central software	
Battery Options	3-cell (31Whr) Lithium Ion battery with ExpressCharge™ 4-cell (45Whr) Lithium Ion battery with ExpressCharge™	3-cell (34Whr) Lithium Ion battery with ExpressCharge™ 4-cell (47Whr) Lithium Ion battery with ExpressCharge™
Power Options	65 Watt or 90W AC Adapter 65W BFR/PVC Free AC Adapter 90W Auto/Air DC Adapter (optional)	
Connectivity	10/100/1000 Gigabit Ethernet **Wireless LAN and WiMAX Options:** Intel® Centrino® Advanced -N + WiMAX 7260 Dell Wireless 1601 (802.11n 2x2, + Bluetooth & WiGig) Dell Wireless 1506 (802.11g/n 1x1, no Bluetooth) **Mobile Broadband[11] & GPS Options:** Dell Wireless™ 5570 HSPA+ Mini Card Dell Wireless™ 5808 LTE Mobile Broadband	
Ports, Slots & Chassis	Network connector (RJ-45), USB 3.0 (3), Stereo headphone/Microphone combo jack, Docking Connector, mDisplayPort, HDMI, 1 Full and 2 Half Mini Card Slots Optional SmartCard Reader/Contactless SmartCard Reader/Fingerprint Reader or FIPS Fingerprint Reader	
Dimensions & Starting Weight[1]	Width: 12.2"/310.5mm Height: .79"/20.0mm Depth: 8.3"/211.0mm 2.99lbs/1.36kg (with 3-cell battery)	Width: 13.2"/337.0mm Height: .8"/21.0mm Depth: 9.1"/231.5mm 3.6lb/1.63kg (with 3-cell battery)
Regulatory and Environmental Compliance	Regulatory Model: P22S Regulatory Type: P22S001	Regulatory Model: P40G Regulatory Type: P40G001
	ENERGY STAR 5.2-qualified (Windows OS) EPEAT Registered. For specific country participation and rating, please see www.epeat.net BFR/PVC-Free[10]	
Input	Single Pointing Keyboard: Standard or Backlit Multi-touch Touchpad	Dual Pointing Keyboard: Standard or Backlit Multi-touch Touchpad
Systems Management	Intel® vPro™ Technology's advanced management features (optional, requires Intel WiFi® Link WLAN)	
Configuration Services[5]	Factory Image Load, BIOS Customization, Hardware Customization, Asset Tagging and Reporting	
Recommended Accessories	On the go: Dell Executive leather carrying case, Dell mDP to VGA adapter, Dell HDMI to VGA adapter, Dell UltraMobile projector, Dell 90W Auto/Air charger with power cord In the office: Dell E-series Port Replicator or D5000 WiGig Dock, UltraSharp Monitors, Dell Wireless Keyboard and Mouse	

Discover the most secure and manageable Ultrabook at Dell.com/Latitude

1 Based on Dell lab testing. Weights vary depending on configuration and manufacturing variability.
2 Some items will be available post-launch. Offering may also vary by country and by configuration. For complete details, refer to the Technical Guidebook available on dell.com.
3 The Dell notebook portfolio contains Corning Gorilla Glass 2 and Corning Gorilla Glass NBT on select systems - See product specification for details
4 Requires an Intel wireless card, a compatible Media Adapter (sold separately) and an HDMI or composite AV-enabled display
5 Availability and terms of Dell Services vary by region. For more information, visit www.dell.com/servicedescriptions.
6 Significant system memory may be used to support graphics, depending on system memory size and other factors. GB means 1 billion bytes and TB equals 1 trillion bytes; actual capacity varies with preloaded material and operating environment and will be less.
7 A 64-bit operating system is required to support 4GB or more of system memory.
8 Intel Rapid Start requires a Solid-State Drive (SSD) or properly configured HDD + SSD
9 Intel Smart Response Technology requires a 32GB SSD setup as secondary storage device.
10 Dell Latitude laptops are brominated flame retardant free (BFR-free) and polyvinyl chloride free (PVC-free); meeting the definition of BFR-/PVC-free as set forth in the iNEMI Position Statement on the 'Definition of Low-Halogen Electronics (BFR-/CFR-/PVC-free)'. Plastic parts contain less than 1,000 ppm (0.1%) of bromine (if the Br source is from BFRs) and less than 1,000 ppm (0.1%) of chlorine (if the Cl source is from CFRs or PVC or PVC copolymers). All printed circuit board (PCB) and substrate laminates contain bromine/chlorine total less than 1,500 ppm (0.15%) with a maximum chlorine of 900 ppm (0.09%) and maximum bromine being 900 ppm (0.09%). Unless specifically stated, external power cords, adapters, peripherals and service parts are excluded.
11 Mobile Broadband: Subject to wireless provider's broadband subscription and coverage area; additional charges apply.

MineProbe: A Distributed Mobile Sensor System for Minefield Reconnaissance and Mapping in Egypt

http://www.mineprobe.org/

Annex 5

WP-2.1: Challenging Aspects of Rough Terrain

T2.1.1: Types of Terrain in Egypt

Technical Report prepared by

Mohammed Ashraf

Applicant/Partner

InnoVision Systems

October 19 , 2015

Content

1. Executive Summary

The selection of a locomotion system is crucial for the performance of an unmanned vehicle and whether it will be successful in its tasks. This task will study the different how the terrain-related challenges highlighted in T1.1 will affect the design of a locomotion system capable to handle these challenges.

2. Soil Classification:
Naming and Grouping Soils Together

Due to the growth of the soil conservation and alternative land uses from agriculture, there were numerous types of soil classification systems around the world.
These systems can be grouped into two main categories depending on various aspects as follows:

2.1 – Natural Classifications:

In this classification criteria , the soil types are grouped depending on some intrinsic properties, behaviour or origin without reference to any particular use

- **Group by Ecologically important characteristics,** such as soils of savannah or tropical rainforest.
- **Group by Origin,** where a common development depending in the interpretation of soil-forming factors and soil genesis, is presumed.

2.2 – Technical Classifications:

In this classification criterion, the soil types are grouped according to some properties or functions that relate directly to a proposed purpose. Examples include:

- **Hydrological:** depending on water regimes such as drainage classes
- **Agricultural suitability:** Group soil types according to their ability to support specific crops or agricultural activities.
- **Land use capability:** depending on the land management capacities
- **Fertility:** availability of essential nutrients.
- **Engineering:** Group soil types according to their bearing strength and behavior under different moisture conditions

Since the soils is very complex for a single classification to be applied globally, there is no single , universally used classification system that can be considered. Therefore many countries have their own trials and approaches to classify souls based on their national concepts and approaches they use to make use from the soils they have.

3. World Reference Base for Soil Resources (WRB)

In the 1970s and ’80s, the FAO and the United Nations Educational, Scientific and Cultural Organization (UNESCO) prepared a legend for the 1:5 million soil map of the world, broadly based on the main soil-forming factors. This map was used by many UN sponsored projects and, over time, many countries modified and adopted the legend to fit their particular needs [61].

Consequently, many of the soil units used in the FAO system are known in many countries and have similar meanings.

The World Reference Base for Soil Resources (WRB) was developed under the auspices of the International Union of Soil Science, by building on the foundations of the FAO legend, to create a common basis for correlating the soil resources of different countries [63].

The WRB places all types of soil within thirty-two major soil groups with a series of uniquely defined qualifiers for specific soil characteristics. **To simplify the study, since it is not intended for geological researches , we constructed a map with Three layers , each layer contain specific data set , in order to discover which types of soil we will face in the demining process of the contaminated areas in the North-West Coast as follows :**

- <u>Layer 1 – World Reference Base (WRB) soil types Layer : </u>in this layer , we referred to the Atlas of Africa to overlay the soil types over the Egyptian map
- <u>Layer 2 – Satellite Global Map from Google maps :</u> we used this layer in order to map the terrain and known roads to the WRB layer.
- <u>Layer 3 – Explosive Remnants of War (ERW) in North-West Coast map : </u> In this map , we overlaid the regions that are contaminated with Landmines and UXOs , and also the cleared areas by the Egyptian army.

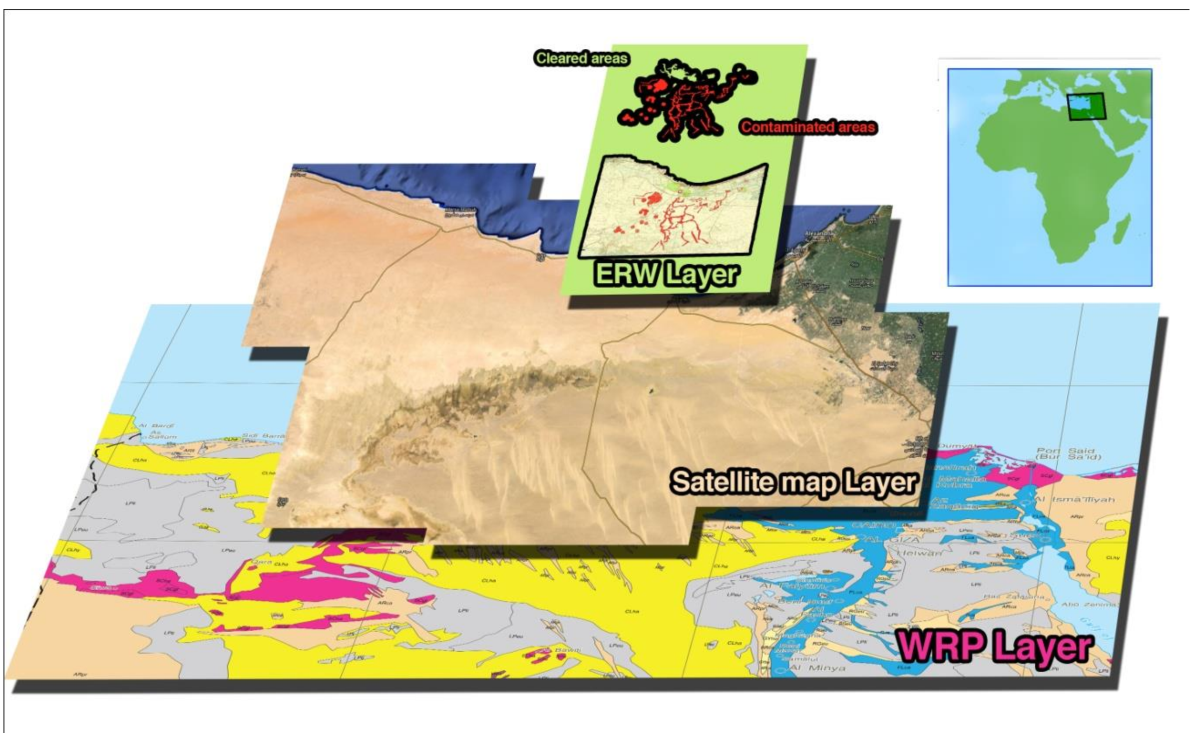
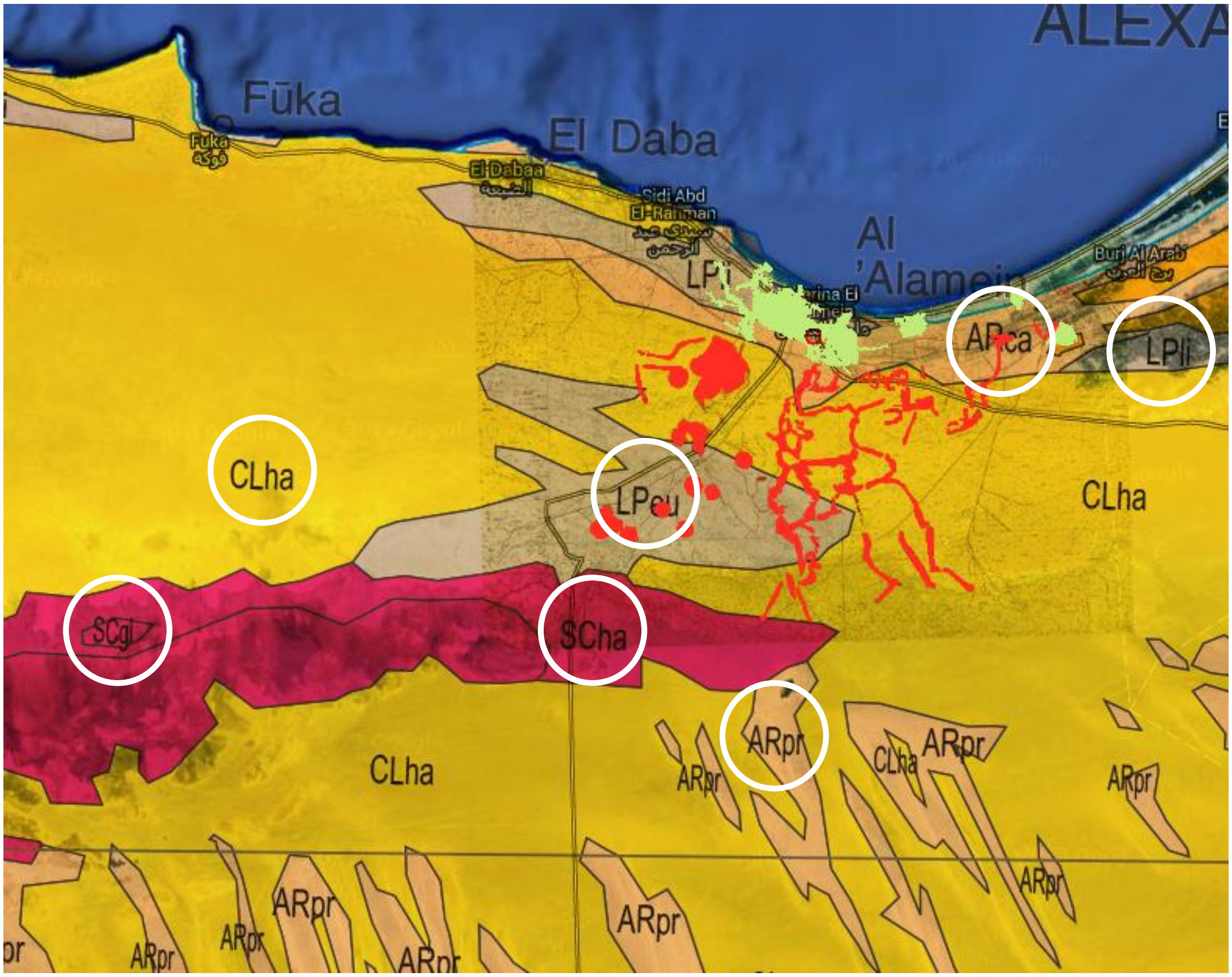


Figure 1 – Layers of Mineprobe soil study map

4. Soil Types in the North-West Coast Area

According to the below overlaid map, there are 4 main groups of soils in the North-West coast, and 7 soil types:



- **Calcisols (**(**from Latin *calcarius*, lime-rich**)**:** This group comprises soil from drier regions with significant accumulation of calcium carbonate. The Calcisols are dominant in Africa covering 6% of the total area of the continent. They form through the leaching of carbonates from the upper part of the soil which precipitate when the subsoil becomes oversaturated, from carbonate rich water moving through the soil or by the evaporation of water which leaves behind dissolved carbonates. Precipitated calcium carbonate can fill the pores in the soil, thereby acting as a cementing agent, and can form a solid hard pan (calcrete) that is impenetrable to plant roots. In our study area there is only one type of Calcisols soil in the North-West Coast:
  - ***Haplic Calcisols (CLha) :*** Very acid with a clay-rich subsoil

- **Arenosols:** Easily erodable sandy soil with low water- and nutrient holding capacity (from Latin, arena, meaning sand). Arenosols develop as a result of the in situ weathering of quartz-rich parent material or in recently deposited sands (e.g. dunes in deserts and beaches). Arenosols cover around 22% of Africa

Above: Attempts to stablise migrating sand dunes in southern Tunisia using date-frond fences. Left unchecked, dune systems can engulf villages and fields.

Left: Deep, sandy soil with thin, clay rich bands in South Africa. Clay migrates through the soil with percolating water and is deposited in bands where the wetting front stops. The presence of these bands enhances the water-holding capacity just enough for crops to survive short dry spells. The holes are burrows. (ISRIC)

In our study area there are two type of Arenosols soil in the North-West Coast:

- ***Calcaris Arenosols (ARca) :*** Sandy soil with notable levels of lime
- ***Protic Arenosols (ARpr) :*** Sandy soil showing no horizon development

- **Leptosols:** Shallow soil over hard rock or gravelly material (from Greek leptos, thin). Leptosols are shallow soils over hard rock, very gravelly material or highly calcareous deposits and have a weak soil structure. Leptosols occur all over Africa, especially in mountainous and desert regions where hard rock is exposed or comes close to the surface and the physical disintegration of rocks due to freeze/thaw or heating/cooling cycles are the main soil-forming processes.

Right: Leptosol from Ethiopia - a cover of debris some 20 cm thick overlies a dolerite. Soil development is slow. Only limited extensive grazing is possible.

Below : Rock outcrops are typical of Leptosol landscapes. Trees must be shallow rooting or develop where the soil is a little deeper and where impeded drainage can lead to higher water retention.

In our study area there are two type of Leptosols soil in the North-West Coast:

- ***Lithic Leptosols (LPli) :*** shallow soil over hard rock having continuous rock close to the surface
- ***Eutric Leptosols (LPeu) :*** Shallow soil over hard rock, not acid

- **Solonchaks:** Soilswith accumulation of salt (from Russian sol, Salt). Solonchaks are strongly saline with high concentrations of soluble salts. They are mostly associated with arid regions and with areas where saline groundwater comes close to the surface or where evapo-transpiration rates are considerably higher than precipitation, at least during a large part of the year. Salts dissolved in soil moisture remain behind after the evaporation of the water and accumulate on or just below the surface. Their characteristics and limitations to plant growth depend on the amount, depth and composition of the salts.

***Below**:* A salt flat with Halophyte vegetation in Namibia. Recent water has evaporated leaving a distinctive 'puffed' up surface that collapses if walked upon.

Right: A Solonchak from southern Morocco. The white surface layer with a thickness of about 50 cm is very rich in soluble salt derived from slightly saline groundwater at a depth of 5 m which comes to the surface by capillary rise.

In our study area there are two type of Solonchaks soil in the North-West Coast:

- ***Gleyic Solonchaks (SCgl) :*** Soil with accumulation of salt showing waterlogged conditions
- ***Haplic Solonchaks (SCha) :*** Soil with accumulation of salt showing no major characteristics.

PHYSICAL CHARACTERISTICS FOR SOILS UNDER STUDY

On Going

REFERENCES

1. Joint Research Centre – European Soil Data Centre (ESDAC) - Africa Soil Atlas – Part 1: http://esdac.jrc.ec.europa.eu/library/Maps/Africa_Atlas/Documents/JRC_africa_soil_atlas_part1.pdf
2. Joint Research Centre – European Soil Data Centre (ESDAC) - Africa Soil Atlas – Part 2: http://esdac.jrc.ec.europa.eu/library/Maps/Africa_Atlas/Documents/JRC_africa_soil_atlas_part2.pdf
3. Joint Research Centre – European Soil Data Centre (ESDAC) - Africa Soil Atlas – Part 3: http://esdac.jrc.ec.europa.eu/library/Maps/Africa_Atlas/Documents/JRC_africa_soil_atlas_part3.pdf

Annex 6

Design of Robot Wheels for Rough Terrain

A Multi-criteria Optimization Approach

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***Abstract*— Unmanned Ground Vehicle (UGV) design problem includes several parameters that should be addressed in order to build a system able to negotiate rough terrains. The selection of the appropriate wheels for the vehicle and its related parameters is a very crucial step in the UGV design process. The wheel is the prime responsible for supporting the robot's overall weight, as well as negotiating the terrain, and its interactions. This paper presents a multi-criteria optimization approach to the wheel design.**

***Keywords*—humanitarin demining, landmines, UXOs, North West Coast, Socio-Economic Impact.**

I. Introduction

In the humanitarian demining domain, UGVs should be able to navigate through rough terrain. This urges the need to carefully design the locomotion system of the vehicles to guarantee motion fluidity. Vehicle locomotion is the study of how to design vehicle appendages and control mechanisms to allow robots to move fluidly and efficiently [1]. Different kinds of locomotion systems are available with different levels of complexities and motion fluidity and efficiency. Unmanned ground or aerial vehicles can be used for minefield reconnaissance and mapping. Each locomotion system has its properties, complexity, limitations and cost. Unmanned ground vehicles can be wheeled, legged or hybrid. Wheeled robots include but are not limited to differential drive, tricycle drive, Ackerman steering, synchro drive, omnidirectional drive, Multi-Degree-of-Freedom (MDOF) vehicles, MDOF vehicle with compliant linkage or tracked vehicles. Legged robot can be uniped, biped, tripod, pentapod, quadruped or hexapod robot. Any types of hybrid locomotion can also be used. Examples of hybrid locomotion include a vehicle equipped with tracks for fast locomotion, and legs for more difficult terrain or flippers with self-cleaning tracks or legged vehicles with driving wheels attached to the end of each leg. Several research efforts such as [2] investigated the possibility to design and develop a robotic controlled vehicle and its utilization in landmine detection and marking the locations of detected mines. Other researchers focused more on the different factors affecting the metal detection capacity of sensors fixed on top of a mobile robotic platform such as described in [3]. Doriya et al proposed in [4] an architecture to be used by warms of robots to successfully scan and detect landmine fields. The coordination and communication of robot swarms is investigated, and several experiments are conducted under the framework of detection of landmines in an uneven terrain.

The biggest challenge for mobile sweepers is that landmines are seldom laid on even, at surfaces; because landmines are always found in outdoor environments that are generally difficult for mobile robots such as, sandy soils or rocky with obstacles some steep inclines, ditches and culverts that can be difficult to negotiate by the vehicle. In order for mobile sensors to move smoothly in the desert, certain features must be available in the locomotion system. Some of these features are reliability; meaning that the vehicles should be able to work in a wide range of temperatures and environmental conditions [5]. Another feature is maneuverability; where the vehicle should be able to surmount most of the obstacles in its way while circumnavigating those which are impassable [5]. Different kinds of locomotion systems are available with different levels of complexities and motion fluidity and efficiency.

This paper presents a Differential Evolution (DE)-based multi-criteria optimization approach to the wheel design. The remainder of the paper is organized as follows. Section II presents wheel design problem formalized as a multi-criteria optimization problem. The proposed DE-based approach is described in Section III followed by describing the conducted experiments and discussing the obtained results in Section IV. Finally, conclusion and future work are summarized in Section V.

II. Wheel design: Problem Formulation

Wheel design problem can be treated as a multi-objective multivariate decision making problem. In this approach, a set of controllable decision variables with a set of constraints and multiple objectives or key performance indicators are used. The problem is stated as following:

Find X which optimizes f

Subject to a possible set of equality and inequality constraints:

$g_i(\mathrm{X}) \leq 0, \quad j = 1,2, \dots, m$

$l_i(\mathrm{X}) = 0, \quad j = 1,2, \dots, p$

where

X is the decision variables, $\mathrm{X} = \{x_1, x_2 \dots, x_5\}^T$

where

x_1= wheel diameter, $x_1 \in [4, 8.2]$ inches;

x_2= breadth width, $x_2 \in [3, 5]$ inches;

x_3= wheel loading, $x_3 \in [22, 24]$ pounds per wheel;

x_4= vehicle speed, $x_4 \in [0.5, 0.7]$ m/s and

x_5= contact area;

The conflicting objectives functions are as follows:

$$f = \{f_1, f_2 \dots, f_5\}^T$$

where

f_1= wheel sinkage, which is the maximum sinkage of the wheel in the soil that it is moving on;

f_2= motion resistance, which is the overall resistance faced by the UGV unit due to the different components of resistance (compaction, gravitational, etc…);

f_3= drive torque, which is the required driving torque from the actuating motors per each wheel;

f_4= drive power, which is the required driving power from the actuating motors per each wheel and

f_5= slope negotiability that represents the maximum slope that can be climbed by the UGV unit considering its weight, as well as the soil parameters;

A number of boundary constraints should also be satisfied such as minimum and maximum wheel width, and diameter, maximum wheel sinkage, torque and power requirements.

A wheeled robot traversing off-road terrain is subject to sinkage. The amount of sink age depends on the geophysical properties of the soil and the dimensions, shape, stiffness and loading of the wheel. Wheels can be classified as rigid or flexible based on how much they deflect under static loading. Rigid wheels retain a constant rolling diameter and cross-section shape under any loading, and include hard metallic wheels or wheels with solid non-metallic tires. For rigid Wheels, the Sinkage equation is as follows:

$$f_1 = \left(\frac{3x_3}{(3-n)(k_c+x_2k_\varphi)\sqrt{x_1}}\right)^{\frac{2}{(2n+1)}} \quad (1)$$

The fundamental equations of sinkage form the analytical basis for estimating the configuration parameters x_1 (Wheel diameter) and x_2 (Wheel width). Solving the above equations for the geometric dimensions of the wheel leads to the following configuration equations of sinkage:

Motion resistance $f_2 = R_c + R_b + R_r + R_g$ (2)

where R_c=Soil compaction resistance given by equation 3:

$$R_c = \frac{\left(\frac{3x_3\cos(\theta)}{\sqrt{x_1}}\right)^{\frac{(2n+2)}{(2n+1)}}}{\left((3-n)^{\frac{(2n+2)}{(2n+1)}}(n+1)(k_c+x_2k_\varphi)^{\frac{1}{(2n+1)}}\right)} \quad (3)$$

R_b= Soil bulldozing resistance is given by

$$R_b = 0.5\alpha x_2(f_1)^2\left(\tan\left(45+\frac{\varphi}{2}\right)\right)^2 + 2cx_2f_1\tan\left(45+\frac{\varphi}{2}\right)$$
(4)

and $\alpha = \cos^{-1}(1-\frac{2f_1}{x_1})$ (5)

R_r= Rolling resistance due to scrubbing in the contact patch and slip, etc.

$$R_r = f_r x_3\cos(\theta) \quad (6)$$

R_g= Resistance due to the gravitational component parallel to the slope

$$R_g = x_3\sin(\theta) \quad (7)$$

f_3= drive torque,

$$f_3 = f_2 \times \frac{x_1}{2} \quad (8)$$

f_4= drive power,

$$f_4 = f_3\left(\frac{2x_4}{x_1}\right) \quad (9)$$

f_5= slope negotiability

$$f_5 = \operatorname{atan}\left(\frac{\mathrm{DP}}{x_3}\right) \quad (10)$$

where DP = Drawbar Pull

H = Soil Thrust

$$DP = H - f_2 \quad (11)$$

III. MULTI-CRITERIA OPTIMIZATION APPROACH

The wheel is the prime responsible for supporting the vehicle's overall weight, as well as negotiating the terrain, and its interactions. Wheel design is a non-trivial multi-criteria optimization problem due to the existence of conflicting objectives or performance indicators and therefore there is no single solution that simultaneously optimizes each objective. In this problem, five decision variables are considered, namely, wheel diameter, breadth width, wheel loading, vehicle speed and contact area. Six conflicting objective functions are considered in this multi-objective contained optimization problem. These objective functions include wheel sinkage, motion resistance, drawbar pull, drive torque, drive power and slope negotiability. Wheel sinkage is the maximum sinkage of the wheel in the. Motion resistance is the overall resistance faced by the UGV due to the different components of resistance (compaction, gravitational, etc.). Drawbar pull is the UGV drawbar pulling force to drive the robot to the front. Drive torque is the required driving torque from the actuating motors per each wheel. Drive power is the required driving power from the actuating motors per each wheel. Slope negotiability represents the maximum slope that can be climbed by the UGV considering its weight, as well as the soil parameters. A number of boundary constraints are considered such as minimum and maximum wheel width, and diameter, maximum wheel sinkage, torque and power requirements. This problem can be solved by two approaches: preference-based multi-objective optimization procedure or ideal multi-objective optimization procedure and Pareto optimization approach [6] [7]. In the former approach, duality principle is applied first to transform all the conflicting objectives for maximization or minimization and then converts these multiple objectives into a single or overall objective by using a relative preference vector or a weighting scheme to scalarize the multiple objectives. However, finding this preference vector is highly subjective and not straightforward. The latter approach relies on finding multiple trade-off optimal solutions and chooses one using higher-level information. This procedure reduces the number of alternatives to an optimal set

of non-dominated solutions known as the Pareto Frontier, which can be used to take strategic decisions in multi-objective space.

Given the fact that the search space of feasible solutions is big in our problem; population-based metaheuristics techniques [8] can be used to find a globally optimal set of solutions at a reasonable computational cost without trapping in local optima. Solving this optimization problem gives the optimal wheel parameters that optimizes or achieves best trade-off between the objectives. Differential evolution (DE) is a population-based metaheuristic used to solve global optimization problems. It approximates the actual global optimum by iteratively mutating and improving the candidate parameters from the initial ones. The DE method cannot guarantee the global optimum is found. The best parameters return depending on the choice of the DE settings as well as the problem itself. The differential evolution solver has the following input parameters.

- **Population size:** is the number of sets of candidate parameters that the solver calculates at each loop iteration in the optimization process. This size also indicates the number of objective function calls at each loop iteration in the optimization process. A larger population size usually results in better optimization results and a longer execution time.
- **Scale factor:** is the diversity factor that the solver uses to generate mutant parameters. Larger values of scale factor result in more diverse mutant parameters.
- **Crossover probability:** is the probability that the solver inherits the trial parameters from the mutant parameters. A larger value of crossover probability results in a higher probability that the solver accepts the mutant parameters.
- **Bounds:** contains the upper and lower numeric limits for the parameters being optimized.
- **Objective function definitions:** Contain the implementation of the objective functions that the solver will run to minimize, by optimizing over the decision variables affecting those objective functions.

Algorithm 1 shows the steps of proposed DE-based approach for wheel design.

Algorithm 1: Differential Evolution (DE)

Input : Boundary constraints of the decision variables
Output: Optimal or near-optimal values of the objective functions

Initialize:
set random initial value within specified lower and upper bounds for each decision variable
set maximum number of iterations $iterations_{max}$
set convergence threshold $conv_{thr}$
begin
  for $(i < iterations_{max}) \cap$ *(improvement in the best individual of each objective function* $\leq conv_{thr}$*)* **do**
    Combine candidate solutions randomly to get mutant solutions
    Crossover candidate parameters with mutant solutions to get trial solutions
    Map trial solutions into specified bounds
    Evaluate objective functions as well as constraint functions for trial solutions
    Select better solutions from trial and candidate solutions for next loop iteration
  % Output
  Return Optimal or near-optimal values of the objective functions

More details about these steps are provided below:

- First, the solver initializes the boundary constraints of the different decision variables (wheel diameter, breadth width, wheel loading, vehicle speed and contact area) by setting lower and upper bound for each decision variable. During the initialization stage, maximum number of iteration and convergence threshold are set to be used as stopping criteria.
- At each iteration, candidate solutions are randomly combines to get mutant solutions. The diversity factor that the solver uses to generate mutant solutions is the scale factor. The larger values of scale factor result in more diverse mutant solutions.
- Crossover candidate solutions with solutions parameters to get trial solutions. The probability that the solver inherits the trial solutions from the mutant solutions is called the crossover probability. The larger value of crossover probability results in a higher probability that the solver accepts the mutant parameters.
- Map trial solutions are then mapped into specific bounds.
- Evaluate objective functions (wheel sinkage, motion resistance, drive torque, drive power and slope negotiability) are calculated as well as constraints are checked for trial solutions
- Select better solutions from trial and candidate solutions are selected to get candidate parameters for next loop iteration.
- Keep repeating until no improvement in the best individual for a specified number of generations and then return the best the obtained optimal or near-optimal solutions.

IV. RESULTS AND DISCUSSION

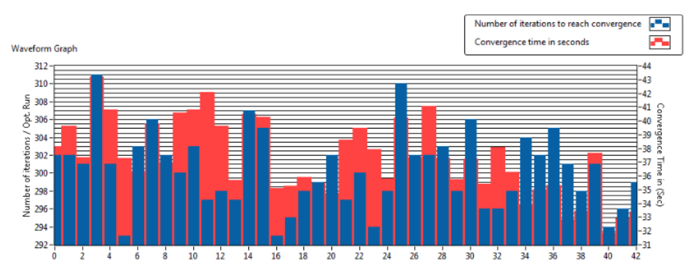
The following subsections describe the experiment setup, evaluation metrics and the experiments conducted to quantitatively evaluative the efficacy of the proposed approach.

A. *Experiment Setup*

An Intel® Core ™ i5, M480 @2.67GHz (4 CPUs) machine with 8192MB RAM and Windows 7 professional 64-bit is used to run the experiments. Each data point is the average of 5 runs.

B. *Evaluation Metrics*

As shown below, the bar plot illustrates the number of iterations and convergence time in seconds for each optimization run



- CPU time till convergence: ranges from 31 seconds to 43 seconds
- number of iterations till convergence: ranges from 292 to 311 iterations
- CPU time per iteration: ranges from 0.106 sec to 0.138

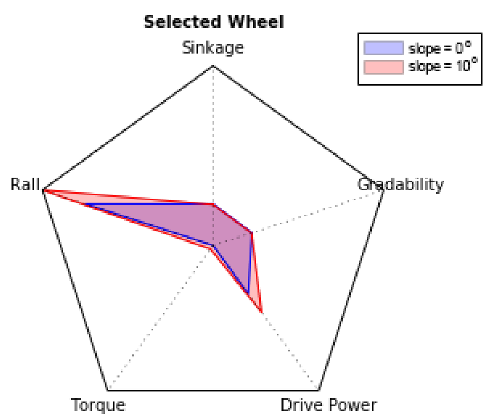
- Experimentation with different algorithm settings (number of population/particles, crossover & mutation rates, scale factor, etc.):
  - As the scaling factor was increased from 0.1 to 0.5 , the solver couldn’t meet the stopping criteria for the Wheel diameter while the Breadth width and Wheel loading found their optimal solution (the stopping criteria met). The Wheel diameter optimal solution had a variance around the mean 0.08 (the stopping criteria was at variance 0.00005). Larger values of the scaling factor results in more diverse mutant parameters.

  - As we increase the crossover probability , we are increasing the probability that the solver accepts a mutant parameter. With such settings it is required to keep the scaling factor low in order to minimize the diversity of the mutant parameters.

  - By increasing the number of population, this leads to longer time till convergence but provides high repeatability for the results (no variations in optimal solution when repeating the optimization runs).

- Experimentation with different values of pre-assigned parameters (slope angle, friction coefficient, velocity, etc.)

  -When increasing the slope angle (10 degrees), additional resistance component will be added (gravitational Resistance equals zero in case of a slope angle of 0, which increases as the slope angle increase), but still the selected wheel geometry based on the selection criteria at section c and as discussed in table 1, performs better than the other wheels.



C. *Experimental Results*

The input ranges of the decision variables resulted in 42 optimization runs to cover the combination of different Wheel diameters with breadth width. Each step in the wheel diameter’s range was managed to meet each step in the breadth width’s range in order to cover all the possible combinations and to come up with the best combination of decision variables that gives minimum sinkage with minimum rolling resistance; acceptable amount of rated torque; minimum drive power requirements and maximum slope negotiability. For each of the major decision variables we monitor the mean and standard deviation using the probability density function plot. As the optimization iterations moves towards convergence (the stopping criteria is to achieve a standard deviation of 0.00005 or less from the mean value for each decision variable) we can monitor the convergence as it progresses.

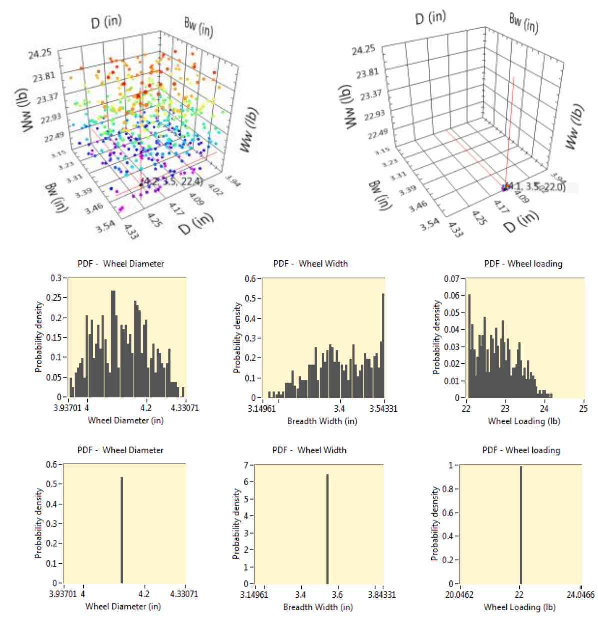


Figure 1. Populations progressing towards convergence (optimal solution)

As shown in figure 1, comparing the left and right 3D scattering diagram indicates that initially the population values are normally distributed over the constraint range. As the iterations progress, the initially random candidate solutions are combined to get mutant solutions. Depending on the scale factor and the crossover probability, the solver decides whether to inherit the trial solutions form mutant solutions. The solver keeps on selecting the better solutions from the candidate and trial solutions until the distribution of the population values starts to be centralized around the optimal solution (Distribution variance around the mean becomes less than 0.00005) for this optimization run.

Table 1 summarizes the obtained results in terms of optimal decision variables and the corresponding objective function values.

TABLE I. OPTIMIZATION RESULTS

Decision Variables		**Objective Functions**	
Wheel diameter	19.4782 cm	Wheel sinkage	19.933 mm
Breadth width	12 cm	Motion resistance	53.00734 N
Wheel loading	10 kg	Drive torque	5.1624 N.m
Vehicle speed	0.5 m/s	Drive power	26.51 Watt
Contact area	0.01522	Slope negotiability	19.7377 degrees

D. *Mixed-initiative Multicriteria Optimization Tool*

A DE-based multi-criteria optimization tool has been developed. This analytical tool allows the user to specify boundary constraints for each decision variables and set the soil type and the expected rolling friction. In addition, user can set other parameters related to the Differential Evolution algorithm

such as population size, optimization stopping criteria (maximum number of iteration and/or a convergence threshold), scale factor and crossover probability. In this tool, different optimal solutions are visualized in an interactive graphical user interface in form of trade-off curves. Decision maker can explore the alternatives and select the trade-off solution. As shown in Fig. 2, the vertical parallel axes of these trade-off curves represent the 5 objective functions and range preference filters allow the user to control the lower and upper bound of each objective function and decision variables in order to focus on a certain range of solutions and filter out other solutions.

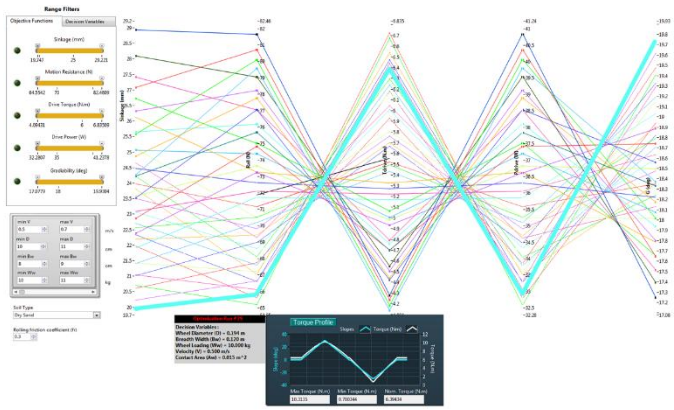


Figure 2. Trade-off cruves of the analytical tool

Lines represent possible candidate solutions and each point on these lines represents specific value of an objective function in this solution and can be rendered for further details. A certain optimal solution known a priori—if available-can be set as a reference in order to facilitate the comparison. The tool also allows for adding custom filers (constraints) to narrow the display of the optimization runs (lines inside the trade-off curve) and filter out the ones that meets these filter ranges. For example, the user may decide that it is only needed to display the trade-off curves of runs between 19 and 20mm sinkage, AND torque ranges between 5.6 NM and 6 NM.

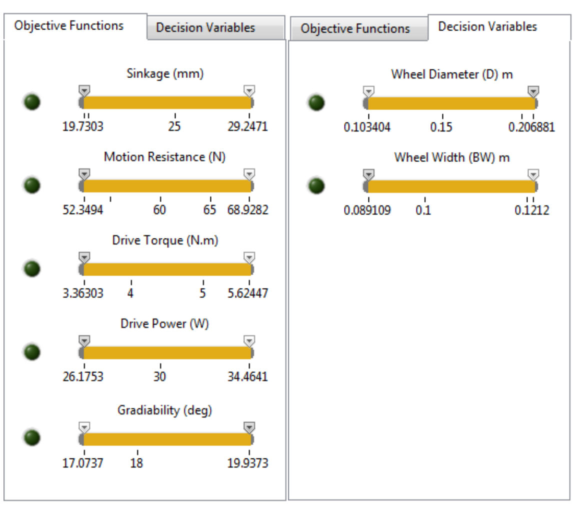


Figure 3. Range filters for Trade-off curvers

The tool also provides a Radar diagram for the selected wheel against the 5 main objective functions we are optimizing on. As shown below the wheel selected has the minimum sinkage across all ranges, provides a high contact area and thus high resistance, allowing for efficient use of torque and power, and provides negotiation with a slopped terrain up to 19 degrees of inclination.

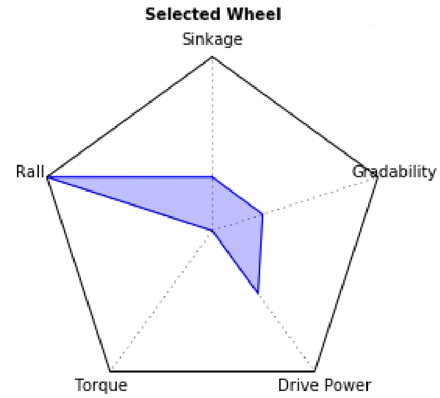


Figure 4. Radar curve for the selected wheel against all objective functions

The tool also allows for changing the constraints, soil type (Dry Sand, Loam, Sandy Loam, Clay, Heavy Clay, Lean Clay), rolling friction value, and Differential Evolution optimization parameters as shown below:

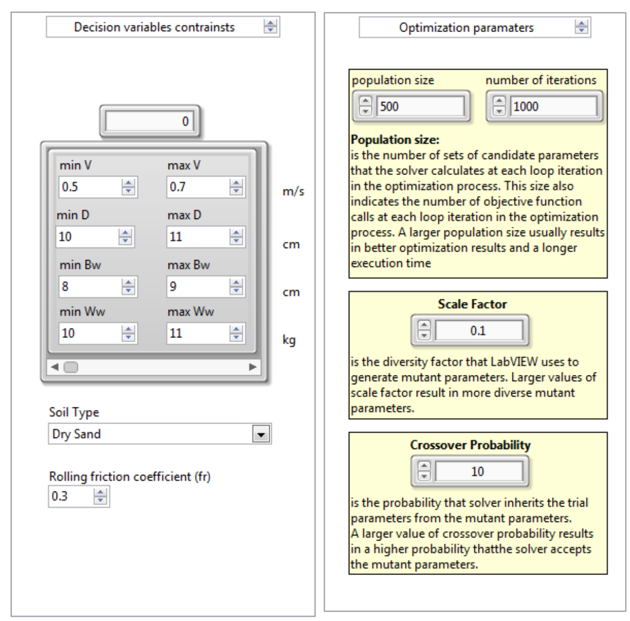
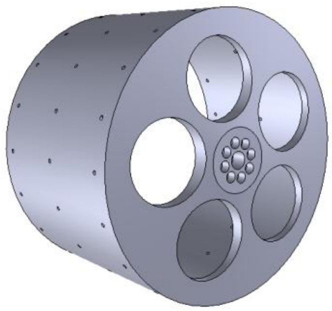


Figure 5. Optimization tool settings

The tool also provides the ability to define a certain stopping criteria. The current settings are to stop the optimization run after certain iterations, or when a certain standard deviation between the population distribution is achieved.

The selected wheel was designed on a CAD tool. The material used is Aluminum alloy 7075 which can withstand high stress and has a significantly lower weight compared to other material options.



In order to increase the traction with the soil, it was decided to have 20 grousers to improve traction all over the surface of the wheel. The selected wheel diameter is distributed into two terms, 18mm for the wheel and 1.47mm for the grousers (2 grousers aligned on the same axis). The surface of the wheel contains threads to ease the fixation and removal of the grousers layers. The grousers are designed to be modular and have multiple fixation points to easily exchange them or modify their design.

Figure 6. Implemented Wheel Design

Currently the wheel is being tested on a specially manufactured test bed for this purpose, and the results will be rendered in a recent future work. The results will include various soil types, different grouser lengths and number, Various slopes, and the involvement of translational velocity which will simulate the effect of other wheels over the wheel under test.

V. Conclusion

Designing of an All-Terrain wheel is a tedious process as the same wheel might perform in a very different way depending on the soil behavior and Terramechanics. For example, the same wheel might experience very different sinkage performance when moving over dry sand soil and clay rich soil. In this paper, the wheel design problem has been treated as a multiobjective multivariate decision making problem. One technique of optimization (Differential Evolution) was applied to optimize over a number of conflicting objective functions that describe the terrain negotiation of a certain wheel geometry. A Trade-off curve helps us study these conflicting objective functions after we optimized over certain geometry range and decide which wheel we may select depending on the application. The study concluded that the selected wheel geometry minimum sinkage values and torque requirements. It also provided an acceptable slope negotiating capabilities. Adding grousers will improve the traction and obstacle climbing capabilities. Future work will include the applying of a multi-objective genetic algorithm (GA) and particle swarm optimization for Pareto optimization (MOPSO), record the optimality (obtained values of decision variables and the corresponding values of the objective functions) after convergence with the same stopping criteria for all the three algorithms (DE, MOPSO and GA-based Pareto), CPU time till convergence, number of iterations till convergence, CPU till per iteration, and including real-world measurements from the test bed.

Acknowledgment

This research was carried out within the framework of “MineProbe: A Distributed Mobile Sensor System for Minefield Reconnaissance and Mapping in Egypt” project (EU-Egypt Innovation Fund - Grant Scheme 1 - EuropeAid/132-715/M/ACT/EG) funded by Research, Development and Innovation (RDI) Programme of Ministry of Higher Education and Scientific Research in Egypt and the European Union.

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MineProbe: A Distributed Mobile Sensor System for Minefield Reconnaissance and Mapping in Egypt

http://www.mineprobe.org/

Research, Development & Innovation Programme

برنامج البحوث والتنمية والابتكار

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Annex 7

WP-2: Locomotion System for Rough Terrain

T2.2.2.2.3: Robotic Arm Design

Technical Report prepared by

Eng. Ahmed Abdel Hamid

Applicant/Partner

InnoVision Systems

May 19, 2016

Annex 4: Consultix Technical Offer

Content

1. Executive Summary

This document is about robot arm selection and design for Mine Detection Rover Robot which should carry the mine detection sensors and perfume scan movements in front of the robot.

2. Robot Arm requirement

The arm should be designed to meet these requirements

- Horizontal Reach: 1 meter in front of the rover
- Vertical Reach: 0.5 in front of the rover
- Height Reach: 0.25 meter close to ground
- Payload: ~ 6 Kg
- Low weight
- Low power consumption

3. Robot Arms Comparison

The most suitable robot arms for our application are Horizontally Articulated Arms such as SCARA (Selective Compliance Articulated Robot Arm) and Vertically Articulated Arms. In order to compare these arms and estimate the arm weight and required power , Solidworks simulation has been used with the following assumptions

- Arms are made from the same material (1060 Aluminum)
- All Arms should not pass half of the yield stress of the material under maximum static load - 27 MPa for 1060 Aluminum –
- The structure displacement under maximum static load shall not be more than 1 mm.
- Motors power estimation calculated based on the torque and speed required for the arm to complete one cycle (Extract, Scan and Retract)

Figure 1: Horizontally Articulated Robot Arm

Figure 2: Vertically Articulated Robot Arm

3.1. SCARA Robot Arm

The SCARA robot arm is a horizontally articulated arm that has many advantages such as deep horizontal reach, good size-to-reach ratio, high positioning mobility and low power requirement to complete a single cycle because most of the payload loading are on the structure. In this mechanism, , motors only need enough power to move the payload on vertical motion, but the arm needs a linear actuator at the end-effector to move the payload up and down which increases the stress on the joints and makes the arm less stable.

Weight Calculation:

- Maximum Stress: 5.46 MPA
- Maximum Displacement: 0.45 mm
- Structure Weight Calculated: 7 Kg

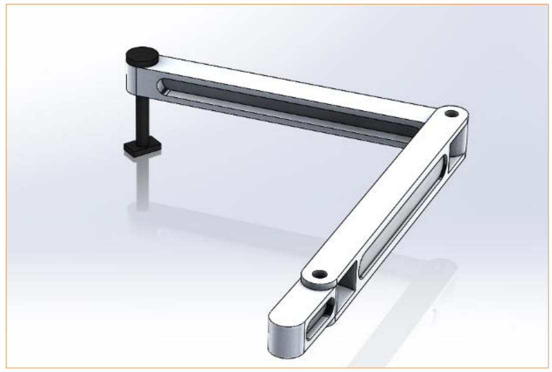

Figure 3: SCARA ARM Design

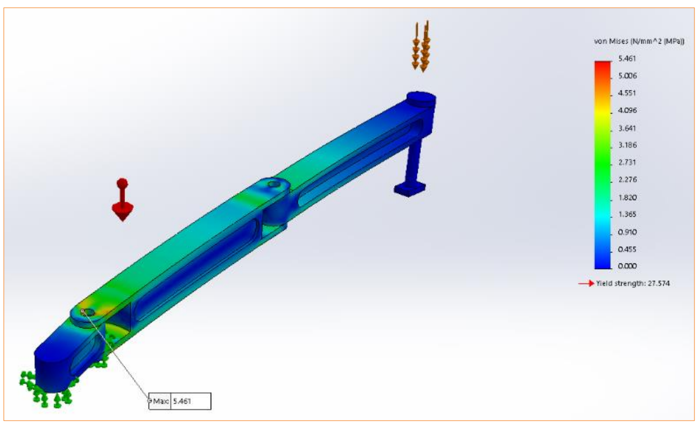

Figure 5: SCARA Stress

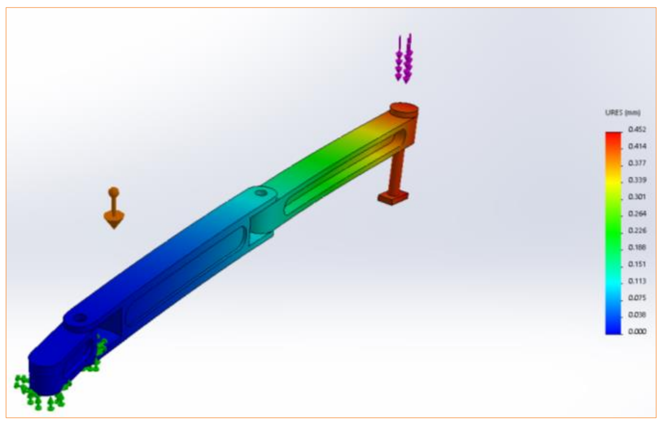

Figure 4: SCARA Displacement

Motors Power Calculation:

- Base Maximum Speed: 4.5 RPM
- Joint Maximum Speed: 7 RPM
- Base Maximum Torque: 1.28 N.m
- Joint Maximum Torque: 0.45 N.m
- Linear Actuator Force: 60 N
- Linear Actuator Stroke: 25 cm
- Linear Actuator Speed: 70 mm/s

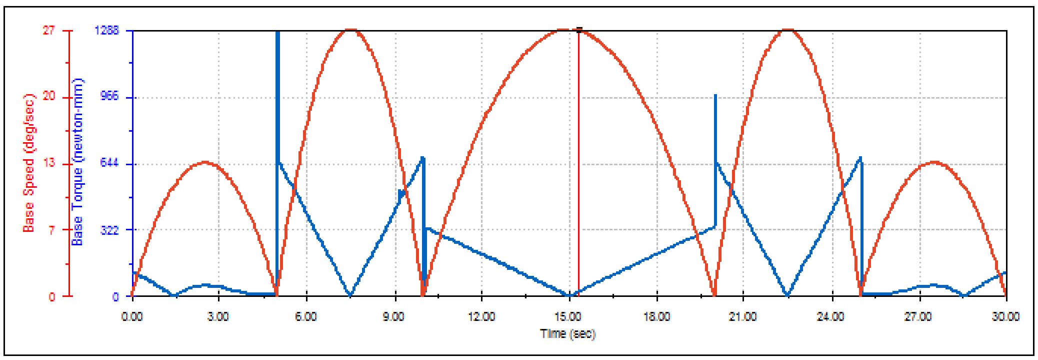

Figure 6: SCARA Base Motor

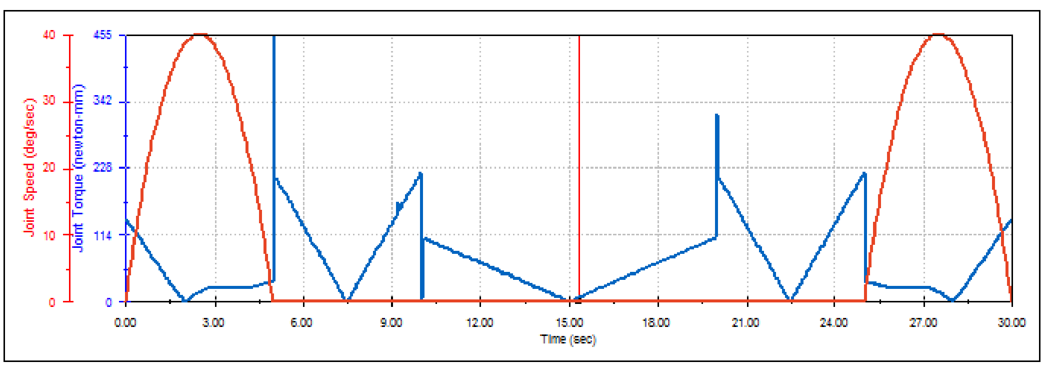

Figure 7: SCARA Joint Motor

Motors Weight Calculation:

- The closest available commercial servo motor for our requirements for Base & Joint: Dynamixel MX-106R Robot Actuator[1]
    - Rated Torque: ~ 2 N.m
    - Rated Speed: ~ 11 RPM
    - Weight: 0.2 Kg
    - Rated Current: 1.3 A
    - Hold Position Current: 1.3A
    - Working Voltage: 12V

- The closest available linear actuator for our requirements: Servocity Heavy-Duty Linear Actuators 10"[2]
    - Rated Force: 110 N
    - Rated Speed: 50 mm/s
    - Stroke: 25.4 cm
    - Weight: ~ 1.4 Kg
    - Rated Current: 2.8 A
    - Hold Position Current: 0 A
    - Working Voltage: 12V

- **Total Motors Weight = (0.2*2) + 1.4 = 1.8 Kg**
- Total Motors Rated current consumption = (1.3 * 2) + 2.8 = 5.4 A
- Total Motors hold position current consumption = (1.3 * 2) + 0 = 2.6 A
- **Total Motors rated power = 5.4 *12 = 63.6 W**
- **Total Hold position power = 2.6 *12 = 31.2 W**

Total Weight = 7 + 1.8 = 8.8 Kg

[1] http://support.robotis.com/en/product/dynamixel/mx_series/mx-106.htm, last accessed: May 26, 2016
[2] https://www.servocity.com/html/25_lbs__thrust_linear_actuator.html#.V0d6rpErKUk, last accessed: May 26, 2016

3.2. Parallel SCARA Robot Arm

The parallel SCARA robot arm is another version of the SCARA but with more rugged structure because the payload is being distributed on 4 links not only 2, but on the cost of more structure weight and less reach.

Weight Calculation:

- Maximum Stress: 6.5 MPA
- Maximum Displacement: 0.5 mm
- Structure Weight Calculated: 11 Kg

Figure 8: Parallel SCARA Design

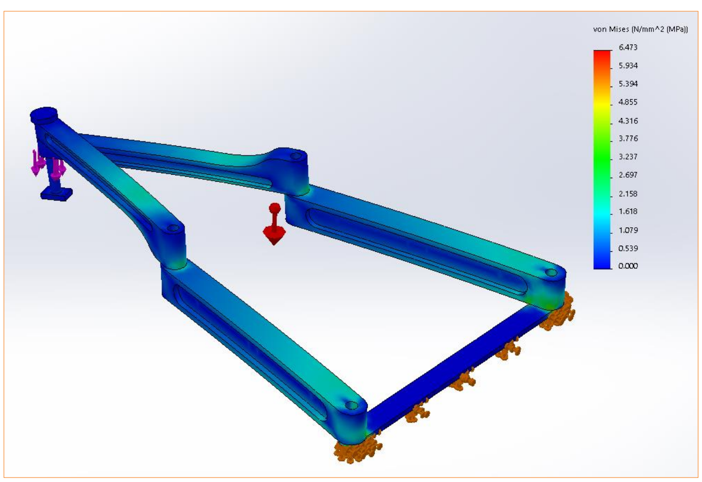

Figure 9: Parallel SCARA Stress

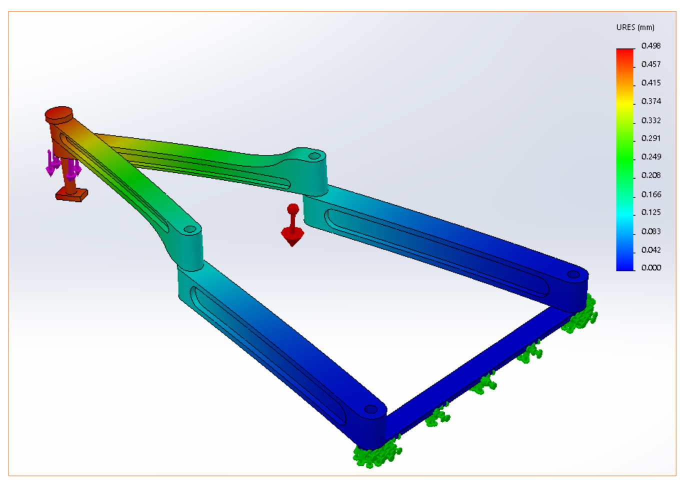

Figure 10: Parallel SCARA Displacement

Motors Power Calculation:

- Right Maximum Speed: 7.5 RPM
- Left Maximum Speed: 7.5 RPM
- Right Maximum Torque: 0.66 N.m
- Left Maximum Torque: 0.83 N.m
- Linear Actuator Force: 60 N
- Linear Actuator Stroke: 25 cm
- Linear Actuator Speed: 70 mm/s

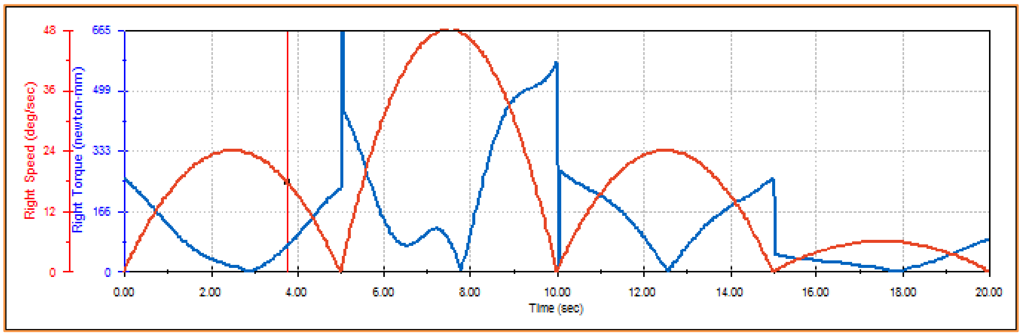

Figure 11: Parallel SCARA Right Motor

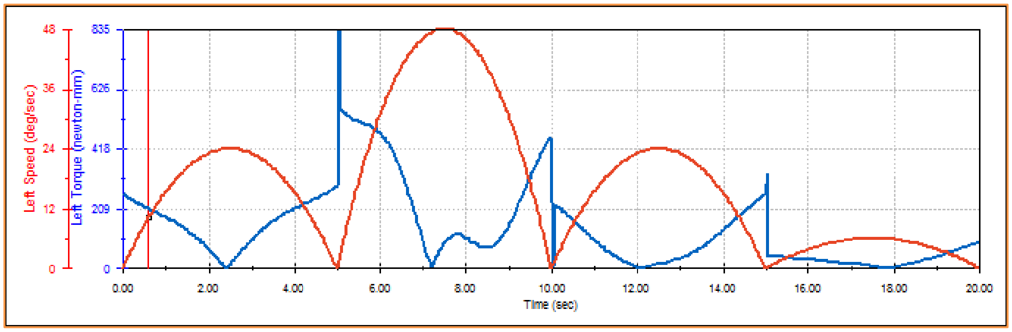

Figure 12 Parallel SCARA Left Motor

Motors Weight Calculation:

- The closest available commercial servo motor for our requirements for Base motors: Dynamixel MX-106R Robot Actuator
  - Rated Torque: ~ 2 N.m
  - Rated Speed: ~ 11 RPM
  - Weight: 0.2 Kg
  - Rated Current: 1.3 A
  - Hold Position Current: 1.3A
  - Working Voltage: 12V

- The closest available linear actuator for our requirements: Servocity Heavy-Duty Linear Actuators 10"
  - Rated Force: 110 N
  - Rated Speed: 50 mm/s
  - Stroke: 25.4 cm
  - Weight: ~ 1.4 Kg
  - Rated Current: 2.8 A
  - Hold Position Current: 0 A
  - Working Voltage: 12V

- **Total Motors Weight = (0.2*2) + 1.4 = 1.8 Kg**
- Total Motors Rated current consumption = (1.3 * 2) + 2.8 = 5.4 A
- Total Motors hold position current consumption = (1.3 * 2) + 0 = 2.6 A
- **Total Motors rated power = 5.4 *12 = 63.6 W**
- **Total Hold position power = 2.6 *12 = 31.2 W**

Total Weight = 11 + 1.8 = 12.8 Kg

3.3. Vertically Articulated Robot Arm

The vertically articulated arms usually consume much more power than SCARA robots because most of the load goes on joints motors. However, power consumption can be improved by using linear actuators as the linear actuator don't consume any power and the load is handled by the power screw inside the actuator at cost of lower speed. In most of the robotic applications including our target domain in MineProbe project, speed of the mechanism is not as important as its torque.

Weight Calculation:

- Maximum Stress: 10 MPA
- Maximum Displacement: 0.44 mm
- Structure Weight Calculated: 3.3 Kg

Figure 13: Articulated Arm Design

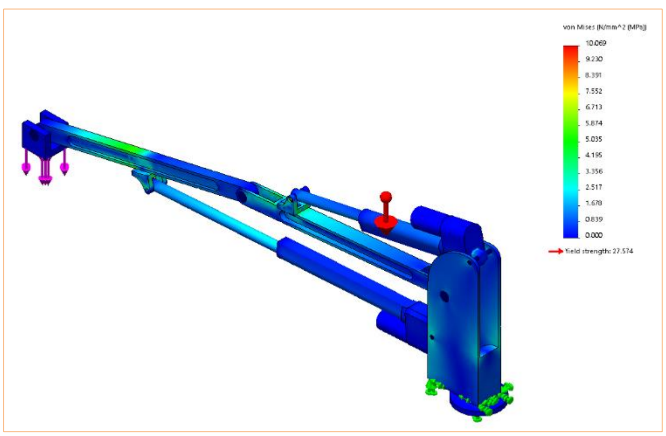

Figure 15: Articulated Arm Stress

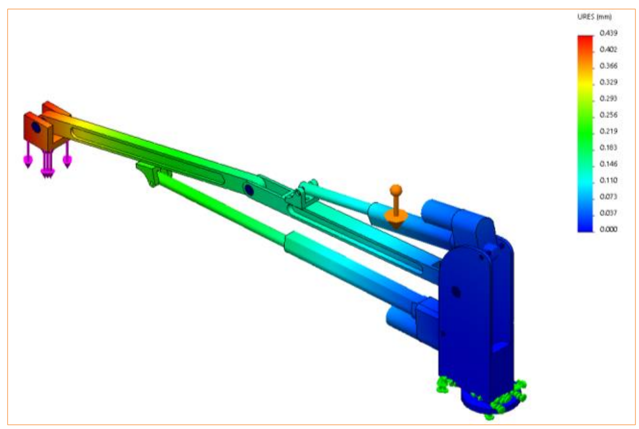

Figure 14: Articulated Arm Displacement

Motors Power Calculation:

- Base Motor Maximum Speed: 4.5 RPM
- Base Motor Maximum Torque: 0.25 N.m

- Fist joint linear actuator Max. Force: 650 N
- Fist joint linear actuator Stroke: 25 cm
- Fist joint linear actuator Max. Speed: 23 mm/s
- Second joint linear actuator Max. Force: 88 N
- Second joint linear actuator Stroke: 20 cm
- Second joint linear actuator Max. Speed: 34 mm/s

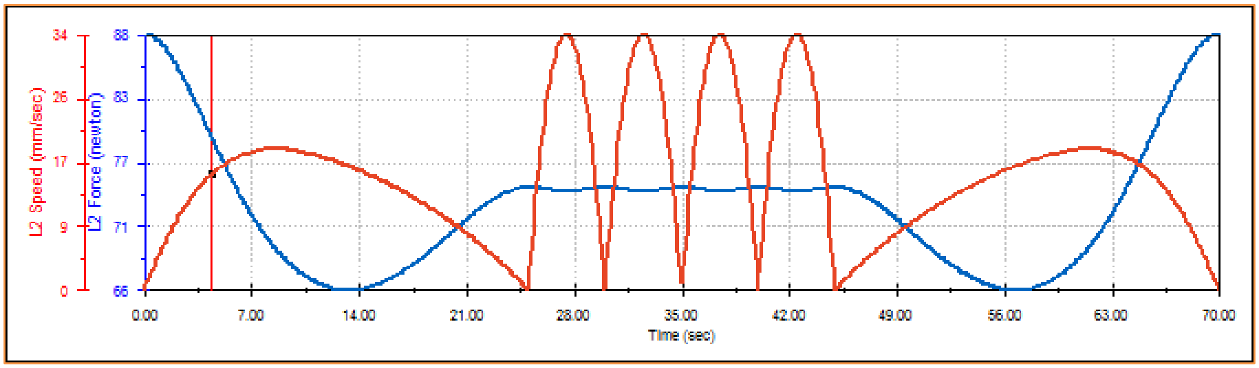

Figure 17: Articulated Arm Linear Actuator 2

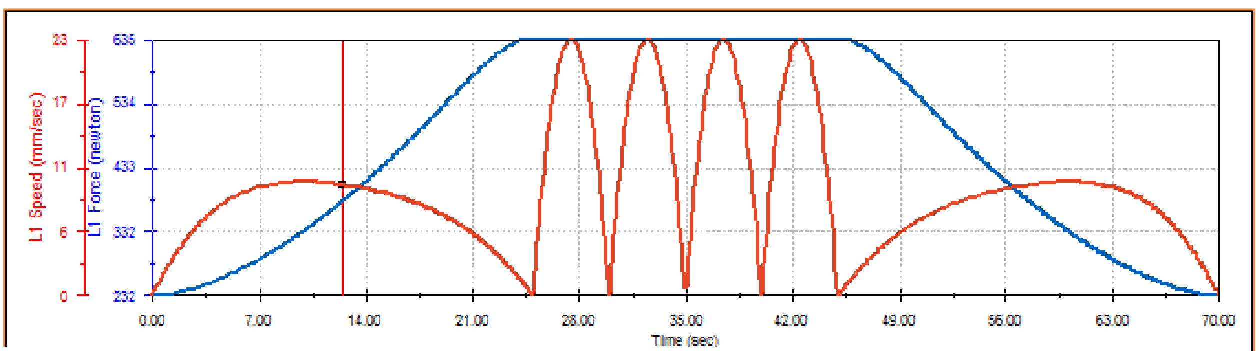

Figure 16: Articulated Arm Linear Actuator 1

Motors Weight Calculation:

- The closest available commercial servo motor for our requirements for Base: Dynamixel MX-106R Robot Actuator
    - Rated Torque: ~ 2 N.m
    - Rated Speed: ~ 11 RPM
    - Weight: 0.2 Kg
    - Rated Current: 1.3 A
    - Hold Position Current: 1.3A
    - Working Voltage: 12V

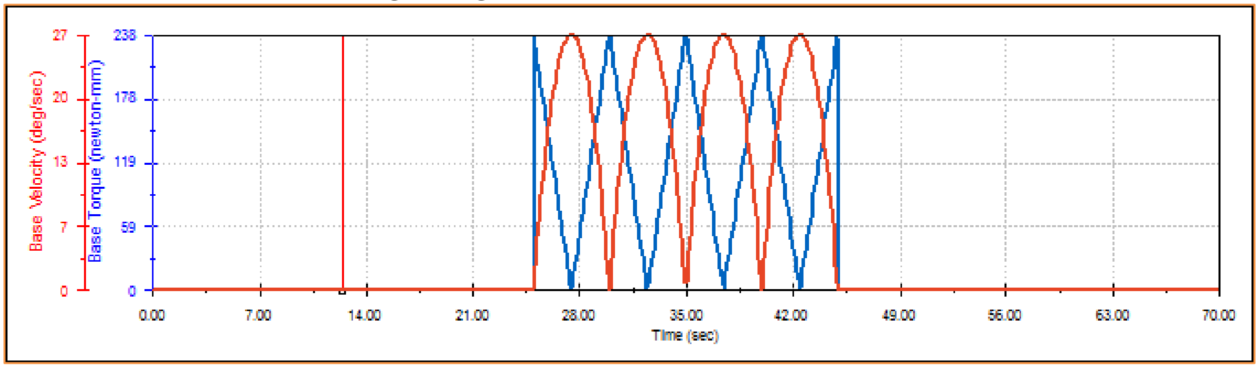

Figure 18: Articulated Arm Base Motor

- The closest available first joint Linear motor for our requirements: Servocity Heavy-Duty Linear Actuators 10"
    - Rated Force: 810 N
    - Rated Speed: 7 mm/s
    - Stroke: 25.4 cm
    - Weight: ~ 1.4 Kg
    - Rated Current: 2.8 A
    - Hold Position Current: 0 A
    - Working Voltage: 12V

- The closest available second joint Linear motor for our requirements: Servocity Heavy-Duty Linear Actuators 8"
    - Rated Force: 500 N

- Rated Speed: 13 mm/s
- Stroke: 20 cm
- Weight: ~ 1.4 Kg
- Rated Current: 2.8 A
- Hold Position Current: 0 A
- Working Voltage: 12V

- Total Motors Weight = 0.2 + (1.4*2) = 3 Kg
- Total Motors Rated current consumption = 1.3 + (2.8*2) = 6.9 A
- Total Motors hold position current consumption = 1.3 + (0*2) = 1.3 A
- **Total Motors rated power = 6.9 *12 = 82.8 W**
- **Total Hold position power = 1.3 *12 = 15.6 W**

Total Weight = 3.3 + 3 = 6.3 Kg

3.4. Comparison Table

Arm	Rated Power Consumption (W)	Hold Power Consumption (W)	Weight (Kg)	Cycle Time (s)	Max Reach (horizontal | vertical | depth) mm	Control Complexity
SCARA	**63.6**	31.2	8.8	**30**	1020 | 1020 | 250	**Simple**
Parallel SCARA	**63.6**	31.2	12.8	**30**	800 | 980 | 250	Medium
Vertically Articulated	82.8	**15.6**	**6.3**	70	**1015 | 1015 | 500**	**Simple**

Figure 19: Comparison Table

3.5. Conclusion

Articulated Arm has been selected for better power consumption at ideal – when the arm is holding position - and lower weight at cost of lower speed which will be improved by changing Linear actuators positions and stroke.

4. Arms Design

4.1. Arm Kinematics

Because the arm is only 2-DOF without the end-effector, arm kinematics can be obtained using a trigonometric solution. The arm can be easily simplified to vertical plane by suppressing the base and do the 2D calculation then add it back again to the equation.

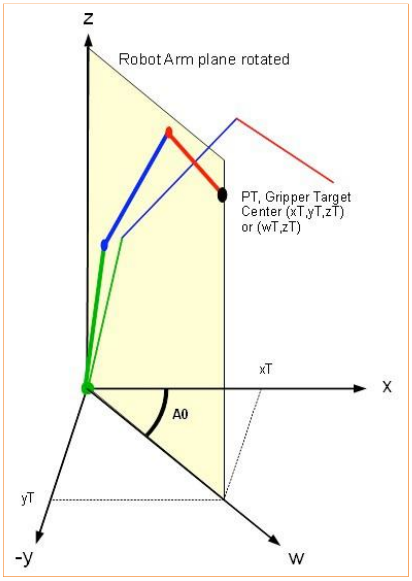

Figure 21: Arm Kinematics 3D

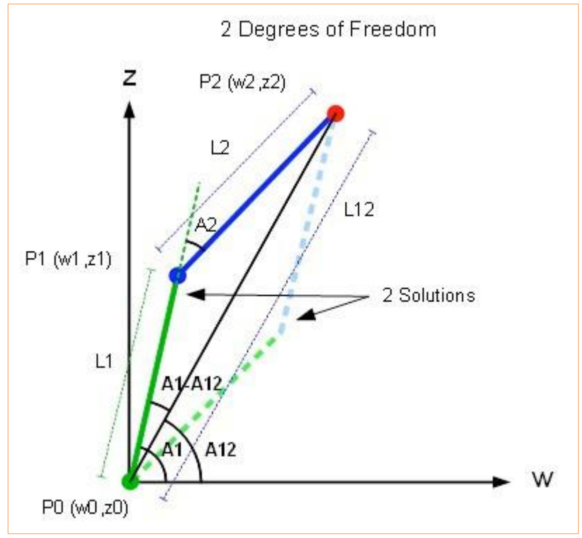

Figure 20: Arm Kinematics 2D

Base Equations:

A0 = arctan (yT / xT)

wT = sqrt (sq (xT) + sq (yT))

2DOF equations:

L12 = sqrt (sq (w2) + sq (z2))

A12 = arctan (z2 / w2)

A1 = arccos ((sq (L1) + sq (L12) – sq (L2)) / (2 * L1 * L12)) + A12

w1 = L1 cos (A1)

z1 = L1 sin (A1)

A2 = arctan ((z2 – z1) / (w2 – w1)) – A1

4.2. Linear Actuators Equations

The last equation was a relation between the end effector position (x,y,z) and the 3 degrees of the joints (A0,A1,A2), but because we are using linear actuators we should calculate the ratio between linear actuators length L1,L2 and their joint angles A1,A2

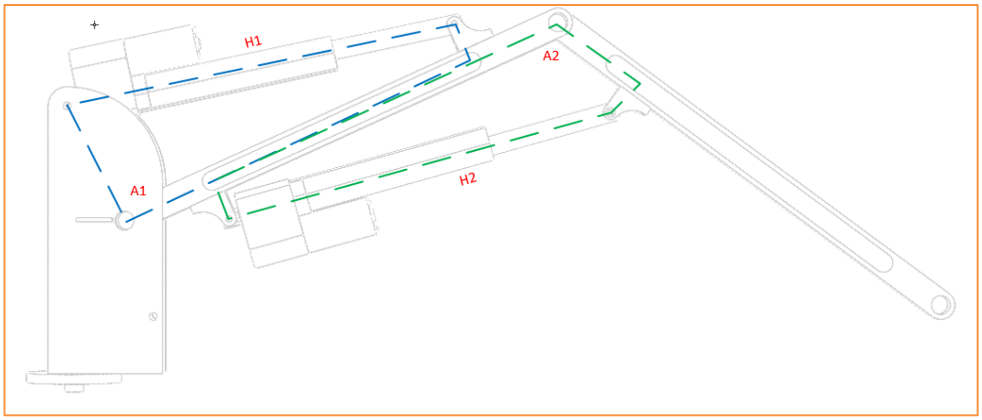

Figure 22: Articulated Arm Linear Displacement to Degree

First Linear Actuator Equation:

a=acos(((y.^2)+(f.^2)-(e.^2))/(2*y*f))

a=a*180.0/pi

c = (b-d-a)*pi/180.0

z=sqrt((x.^2)+(y.^2)-(cos(c)*2*x*y))

Second Linear Actuator Equation:

c = c*pi/180.0;

z=sqrt((x.^2)+(y.^2)-(cos(c)*2*x*y))

a = acos (((x.^2) + (z.^2) - (y.^2))/(2*x*z))

a=a*180.0/pi

b = acos((y.^2 + z.^2 - x.^2)/(2*y*z))

b = b*180.0/pi

*the same equation repeated 3 times for every triangle

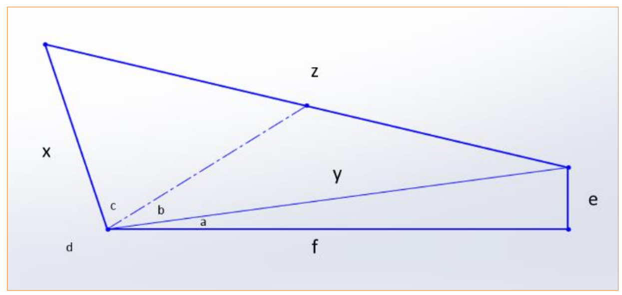

Figure 23: First Linear Actuator Equation

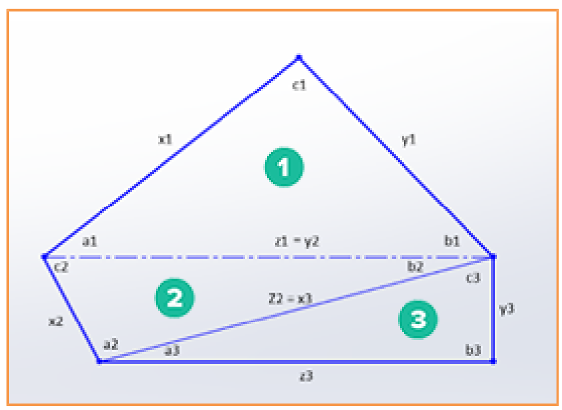

Figure 24: Second Linear Actuator Equation

4.3. Equations Verifying

Solidworks Motion and LabVIEW programming language have been used to verify the kinematics and linear actuators equations

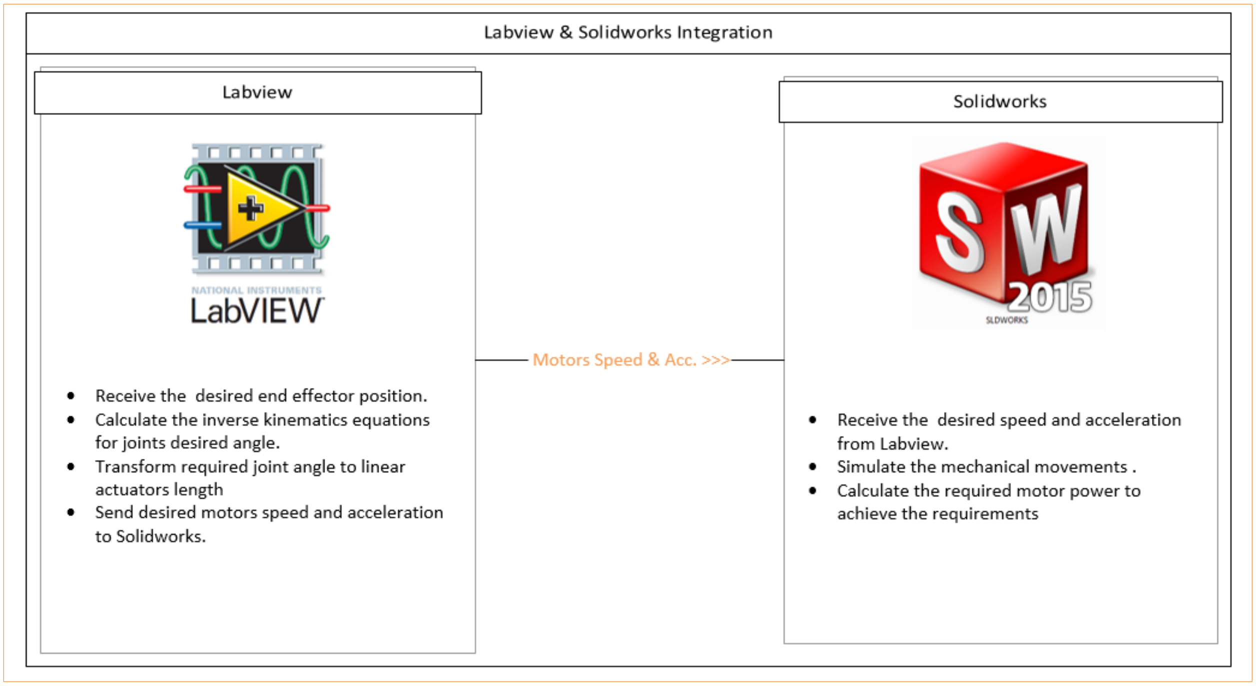

Figure 25: LabVIEW & Solidworks Integration

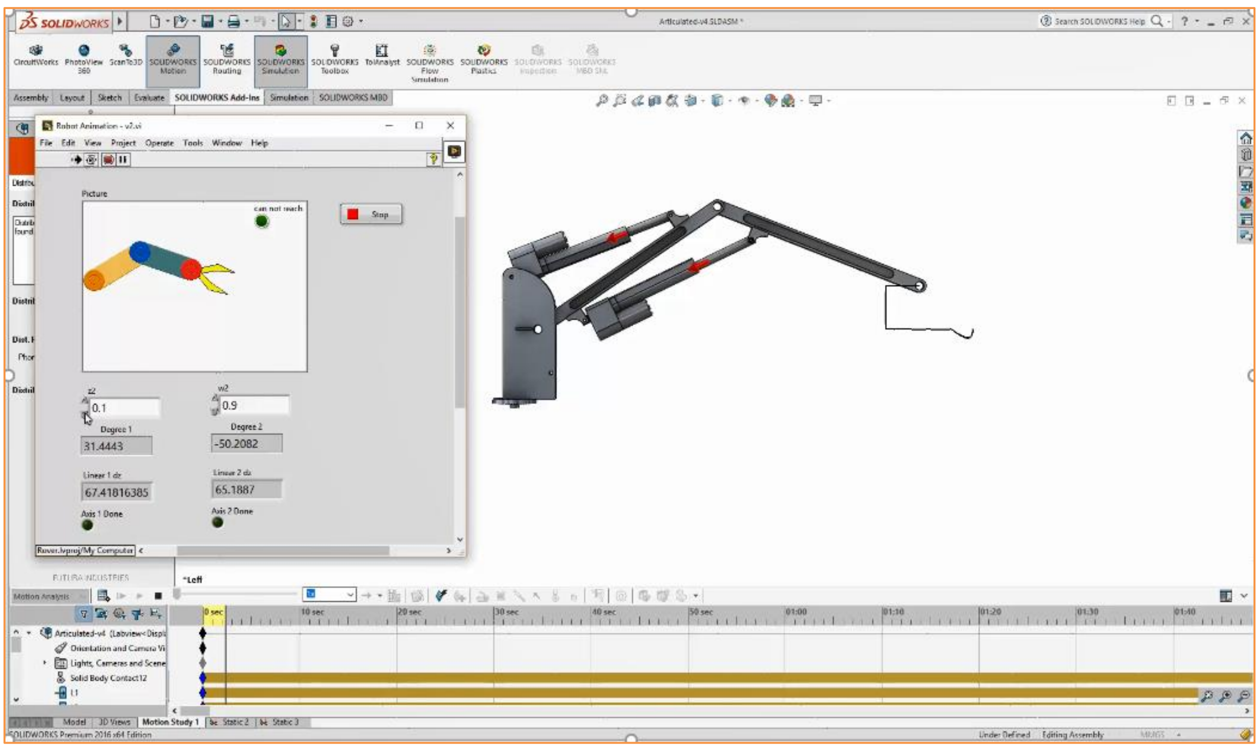

Figure 26: Solidworks Motion with LabVIEW

4.4. Arm Link Structure Design

To select the most rigged and light weight link structure for the arm, comparison has been made between 3 types of structures T-slot aluminum extrusions, aluminum link with 2 slots and aluminum link with truss slots.

Comparison are mad with this assumptions:

- Arms are made from the same material (1060 Aluminum)
- All Links should not pass half of the yield stress of the material under maximum static load - 27 MPa for 1060 Aluminum –
- The structure displacement under maximum static load shall not be more than 1 mm.
- All the links have the same forces and fixation on the simulation.

4.4.1. T-slot aluminum extrusions

- Max Stress: 13.53 MPa
- Max Displacement: 0.44 mm

- Weight: 354 g

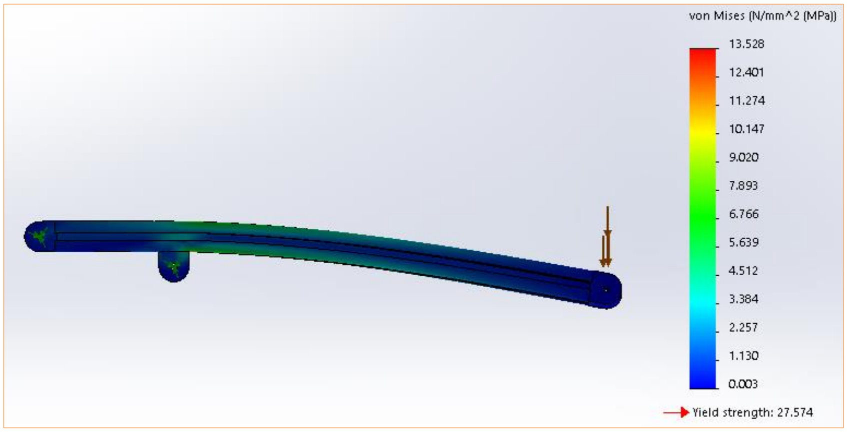

Figure 27: T-Slot Stress

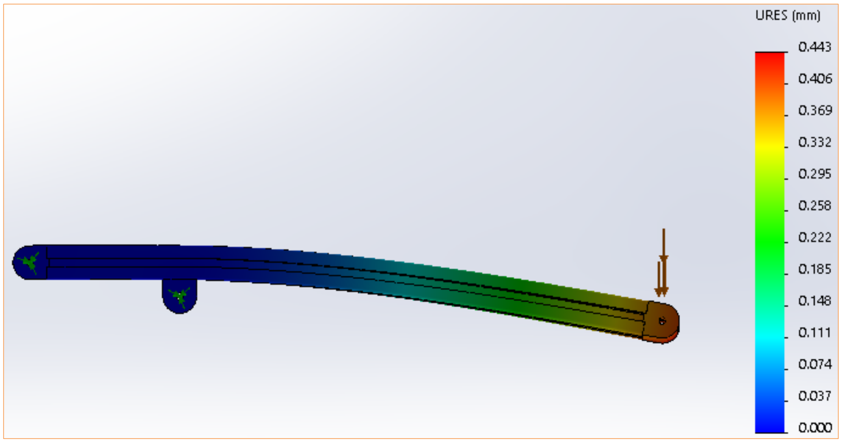

Figure 28: T-Slot Displacement

4.4.2. aluminum link with 2 slots

- Max Stress: 12.6 MPa
- Max Displacement: 0.395 mm
- Weight: 224 g

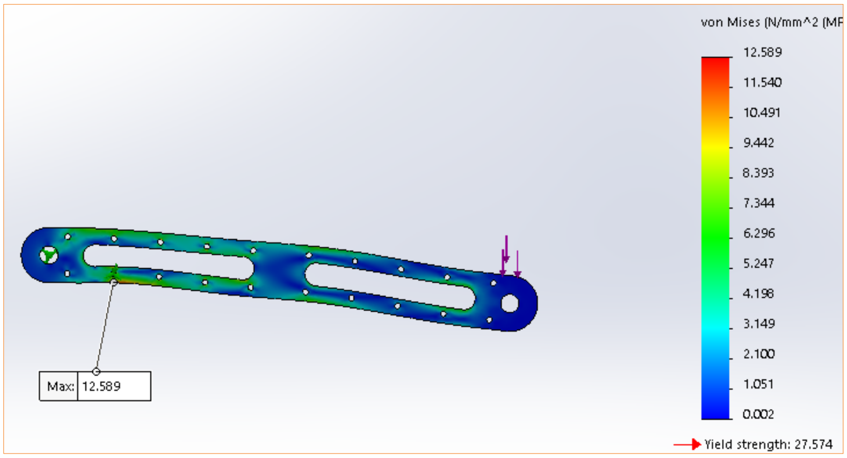

Figure 29: Aluminum Link with 2 Slots Stress

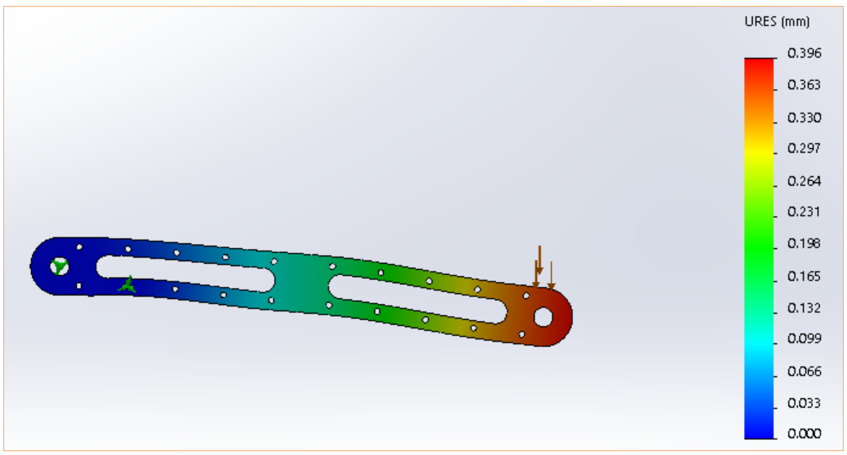

Figure 30:Aluminum Link with 2 Slots Displacement

4.4.3. aluminum link with Truss slots

- Max Stress: 13 MPa
- Max Displacement: 0.280 mm

- Weight: 239 g

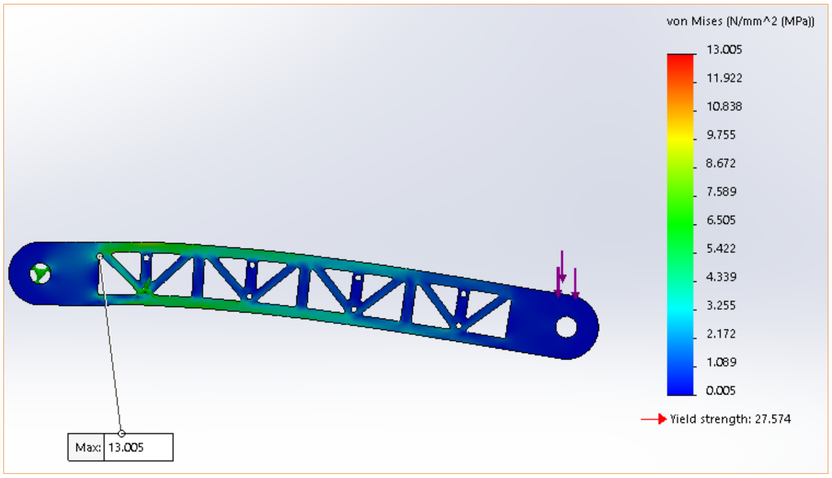

Figure 31: Aluminum Link With Truss slots stress

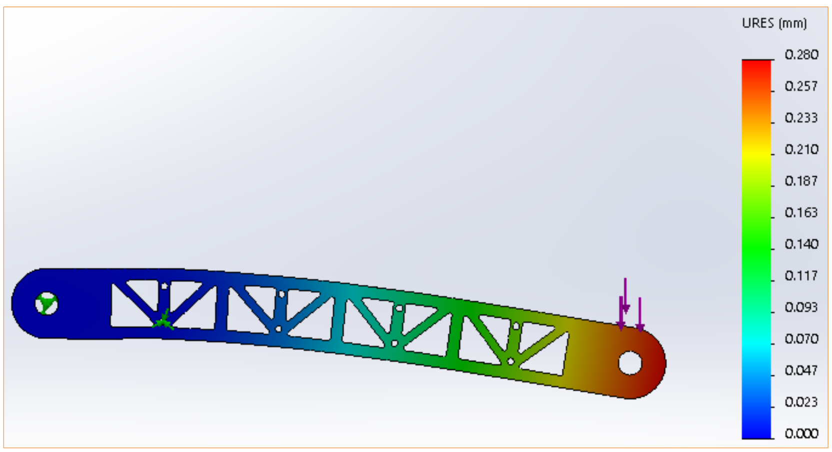

Figure 32: Aluminum Link with Truss slots stress

4.4.4. Comparison Table

	Weight (g)	Stress (MPa)	Displacement (mm)
T-Slot	354	13.52	0.443
Normal Slot	244	**12.58**	0.395
Truss Slot	**239**	13	**0.279**

Figure 33: Structure Links Comparison Table

4.5. Current Arm Design

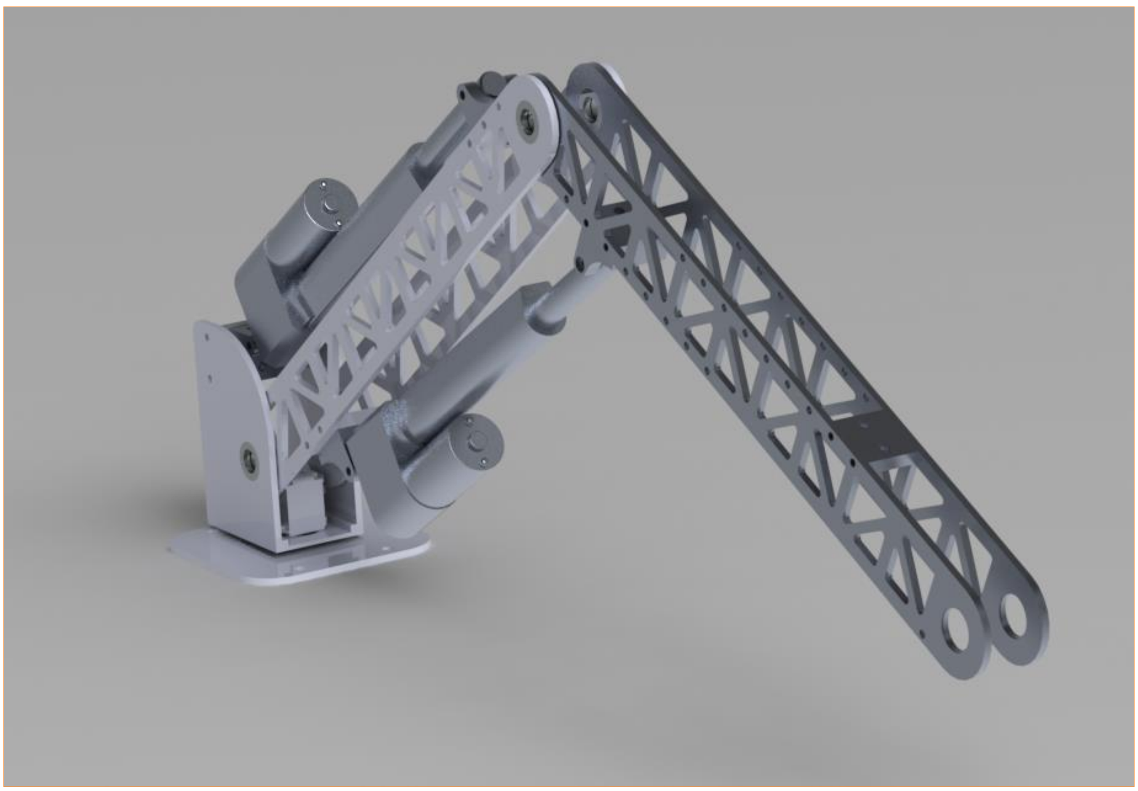

Figure 34: Current Arm Design